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Paper No. 1

INTRODUCTION.

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Christopher Columbus has been called the practical founder of the Panama Canal enterprise, for he was the first to propose a water highway from Europe to Asia, by the Atlantic Ocean; and he believed that he had arrived at the shores of Asia when he reached terra firma at the end of his voyage. His fourth voyage carried him to the northern shores of the Isthmus of Panama, which he skirted for the entire length, and, when informed by the natives that he was nearing a "narrow place between the seas", so intent was he upon his discovery of the "secret of the strait" that he construed the information as meaning a narrow strip of water. His search terminated, however, without the result for which he hoped.

Some ten years later, Vasco Nuñez de Balboa, Governor of Castilla del Oro, having heard from the natives tales of a great sea not far to the south of his settlement near the mouth of the Atrato River, and feeling it incumbent upon him to discover new regions, in order to induce the King of Spain to overlook the irregularities by which he had succeeded to the gubernatorial office, undertook the journey across the Isthmus in quest of the Great South Sea, which resulted in the discovery of the Pacific, on September 25, 1513.

Accompanying Balboa across the Isthmus on this expedition was an engineer, Alvaro de Saavedra Ceron, who, subsequent to the death of Balboa, became one of the lieutenants of Hernando Cortez. Cortez was hopeful of discovering the strait, concern-

ing which he wrote the King of Spain (Charles V) in 1524: "If the strait is found, I shall hold it to be the greatest service I have yet rendered. It would make the King of Spain master of so many lands that he might call himself lord of the whole world". Cortez went further, advocating that if the strait could not be found, one should be made, and subsequently proposed the construction of a canal by the Tehuantepec route.

Alvaro de Saavedra doubted the existence of a strait, and, believing with Cortez that one should be constructed, prepared plans for a canal to be built along the route which he followed with Balboa in 1513. Death overtook him as he was about to lay his plans before the King of Spain.

Subsequent voyages of discovery failed to disclose the natural narrow strip of water. Cortez proposed the construction of a canal, Saavedra prepared plans for one, and for upwards of four hundred years the question was considered at various times by nations, corporations and individuals. Charles V, at Cortez' insistence, had surveys made with a canal in view, but the reports submitted indicated the impracticability of the route—which was undoubtedly true with the machinery and appliances available in those days.

In 1567, Philip II, the successor of Charles V, sent a party of engineers to survey the Nicaraguan route, but the report was unfavorable to the success of the work. Impressed by the representations made in favor of a canal, notwithstanding the unfavorable report, the king, in his perplexity, is said to have laid the matter before the Dominican Friars, who, desirous of obeying the mandates of the king, were, in their ignorance of the problem, in probably a greater state of perplexity, so they turned to the Scriptures for consolation and relief, hitting upon the following verse, which they concluded had a direct reference to a canal: "What God hath joined together, let no man put asunder". With this injunction from the Holy Writ, they reported against the undertaking. This was a sufficiently good argument for King Philip to abandon further consideration of the subject, which was thereafter put aside and not again considered, for death was to be the penalty for any one who sought a better route across the Isthmus than the paved road which had been constructed from Porto Bello to Panama. It seems

strange that, in the 20th century, when progress in the construction of the canal was retarded by the slides which developed, prophets should arise in condemnation of the work, predicting that a connection between the oceans would never be accomplished, as it was in direct violation of the Apostle's injunction.

During the reign of Philip II nothing further was done looking to an artificial strait, but the subject was revived in 1616, when Philip III ordered the Governor of Castilla del Oro to make surveys for a canal by way of the Gulf of Darien and the Atrato River; nothing came of the matter, however.

In the meantime, Spain's commerce with the Isthmus became very much embarrassed, by reason of the buccaneers who preyed upon it, and the war between England and Spain made matters even worse. The destruction of Porto Bello and Panama by Sir Henry Morgan in 1668 and 1671, practically destroyed Spanish commerce across the Isthmus, and what little remained was entirely stopped by Captain Sharpe, who, landing in Caledonia Bay, marched over to the Tuyra River and destroyed the town of Villa Maria.

Based upon the report of Lionel Wafer, one of Sharpe's companions on this expedition, after his return to England, William Paterson of Scotland, the founder of the Bank of England, undertook the establishment of a British colony on the Isthmus of Darien, so as to secure to Great Britain, "the keys of the universe, enabling their possessors to give laws to both oceans, and to become the arbiters of the commercial world". Though a colony was established on Caledonia Bay, the site selected was very unhealthful, the English and Dutch East India Companies used their influences against it, the Spaniards and Indians were hostile, and the enterprise ended in failure. Paterson, however, from his observation of the Isthmus, expressed the opinion that a canal was practicable.

It is interesting to note in this connection the observations of Willis Fletcher Johnson in his "Four Centuries of the Panama Canal":

> "In his 'Central America in 1701', he wrote that if such interoceanic communication were established, through its ports would flow at least two-thirds of the commerce of

the East Indies, amounting to not less than $150,000,000 a year; while the time and expense of the voyage to China and Japan, and the richest parts of the East Indies, would be lessened by more than one-half, and the consumption of European commodities in these countries would soon be more than doubled and thereafter would be yearly increased. There is interesting food for speculation in the reminder that Paterson's enterprise was undertaken only a few years before the union of England and Scotland, which occurred in 1707, and in the inquiry of what might have happened, had that union been effected before his undertaking, or had his venture been postponed until after the union. In such case, it is to be assumed, there would have been no effective English opposition to his colony, but, on the contrary, it would have received earnest support from English commerce and from the English army and navy. With such support, it would probably have been successful. The Isthmus of Panama would have become an English colony, and generations ago an Isthmian canal might have been successfully constructed under the British flag''.

Nothing further of note occurred in connection with an Isthmian canal until the latter part of the 18th century, when England entered the lists, and, with Lord Nelson and Baron von Humboldt as its representatives, made a series of examinations having in view the construction of a canal. No less than four different Isthmian routes were given careful consideration—the Tehuantepec, the Nicaragua, the Panama, and the Darien via the Napipa and Atrato Rivers. In addition, other routes in North and South America were considered and included in the report. The four routes mentioned, in their opinion, seemed so favorable as to merit further and more thorough investigation. As the result of Humboldt's inspections and reports, Goethe made this remarkable prophecy:

''I therefore repeat that it is absolutely indispensable for the United States to effect a passage from the Mexican Gulf to the Pacific Ocean; and I am certain that they will do it. . . . I should like to see another thing—a junction of the Danube and the Rhine; but this undertak-

ing is so gigantic that I have grave doubts of its completion. . . . And, thirdly and lastly, I should wish to see England in possession of a canal through the Isthmus of Suez. Would I could live to see these three great works. It would be well worth the trouble to last some fifty years more for this very purpose!''

While the reports of Nelson and Humboldt revived the interest of the commercial world in a canal, Spain from other motives again took up the subject in 1814; feeling that its influence in its Central American colonies was waning, it concluded that something had to be done to secure a closer union with the mother country. Consequently, the Spanish Cortes passed a formal decree for the construction of a canal through the Isthmus for vessels of the largest size, and made provision for the formation of a company to carry through the enterprise. No results followed, and Spain's opportunity to open a highway to the commerce of the world terminated in 1823, when the last of her Central and South American provinces succeeded in establishing their independence. A combination of the Central American provinces resulted, in 1823, in the formation of the Federal Republic of the United Provinces of Central America.

In 1825 the Republic of Central America called the attention of the United States to the subject of an Isthmian canal, requesting the cooperation of the American people, in order that they might share, not only in the merit of the enterprise, but also in the great advantages which it would produce. It was later proposed to hold a congress of different nations at Panama in 1826, and President Adams appointed commissioners to represent the United States. In his letter of instructions to the commissioners, the President expressed the opinion that, should the work be executed, the benefits of it ought not to be appropriated exclusively to any one nation, but should be extended to all parts of the globe, upon the payment of just compensation or reasonable tolls. The Republic of Central America did not await action on the part of the United States, for on June 16, 1826, it invited proposals for the construction of an Isthmian canal, and entered into a contract with Aaron H. Palmer, an American, who endeavored to organize a com-

pany for the purpose, but was unsuccessful. In 1830, the Republic of Central America attempted to have a Netherlands company construct a canal at Nicaragua, but the effort failed.

On March 3, 1835, the United States Senate, acting on a proposal made by the Central American Republic, passed a resolution requesting the President to consider the expediency of opening negotiations with other nations, for the purpose of protecting, by suitable treaty stipulations, such individuals or companies as might undertake the construction of a canal, and of securing forever to all nations the free and equal right of navigating it on the payment of reasonable tolls. Under authority of this resolution, President Jackson sent Charles Biddle to Nicaragua and Panama, with instructions to examine the different routes that had been considered previously, whether for a canal or a railroad, with a view to determining the practicability of the different projects. The mission led to no satisfactory results, and on January 9, 1837, a message was sent to the Senate, that it was not expedient at that time to enter into negotiations with foreign governments with reference to the subject.

In January, 1838, Aaron Clark, mayor of New York City, together with other influential citizens, memorialized Congress in the interest of a canal joining the two oceans, urging the great importance of such a connection, and recommending that negotiations be opened between New Granada, Central America, and the great powers of Europe, for the purpose of entering into a general agreement for the promotion of the project. The memorial was considered by the House of Representatives, resulting in a report which, while recognizing the value that such a connection between the oceans would have, recommended no action except to request the President to open or to continue negotiations with foreign nations, according to the terms of the previous Senate resolution. President Van Buren sent another agent to the Isthmus, Mr. John L. Stephens, who recommended the Nicaragua route as the most desirable, and estimated the cost of a canal at that locality at $25,000,000, but did not think the time favorable for undertaking such a work, because of the unsettled and revolutionary condition of the country.

While the United States was conducting these various investigations, efforts were made to secure concessions for canals, and examinations made to determine the feasibility and cost of different projects. Mexico, in 1824, appointed a commission to investigate the Tehuantepec route. The report was unfavorable to a canal, because of the great difficulties that would be encountered. In 1826, John Bailey was sent out by an English company to survey the Nicaragua route, and negotiated for a concession; though he failed in his main purpose, he remained in Central America, and, in 1837, while employed by President Morazin, determined what he considered the best route for a canal—extending from San Juan (now Greytown) to Lake Nicaragua, across the lake to Lajas, and thence to San Juan del Sur on the Pacific. In 1827, J. A. Lloyd was commissioned by President Bolivar to make a survey of the Isthmus of Panama, in order to ascertain the most feasible line of communication across it, for road or canal. He spent two seasons in exploring the country, and carried his line of levels from Panama to La Braja, a point twelve miles from the mouth of the Chagres. He recommended a new line across the Isthmus, beginning at the Bay of Limon, thence by a canal to the Chagres, up the river to a favorable situation on the south bank of the Trinidad River, thence by railroad to Panama or Chorrera. While he made no recommendation favorable to a canal, he reported that if the time ever came when a canal across the Isthmus might be entertained, the Trinidad River would probably offer the most favorable route.

The Republic of New Granada, in 1838, granted a concession to a French company authorizing the construction of macadamized roads, railroads, or canals, across the Isthmus, with Panama as the Pacific terminus. The company spent several years in making explorations and presented a very attractive report to the French Government, with the view of securing its aid in the undertaking; this report stated that a passage had been found through the continental divide, which was only 37 feet above sea level at Panama. The representations were so surprising that in September, 1843, an officer, Napoleon Garella, was sent to investigate the practicability of cutting a canal across the Isthmus, and to report on the means of effect-

ing it, the obstacles to be overcome, and the cost of the work. He favored a canal as the only adequate means of communication; the route proposed started at Limon Bay, joined the Chagres below Gatun, with a tunnel through the continental divide at elevation 134.5 feet above sea level, and the Pacific terminus was to be the Bay of Vaca de Monte, twelve miles southwest of Panama. Access to the summit level was to be effected by eighteen locks on the Atlantic slope, and sixteen on the Pacific, water to be furnished through canals from the Chagres. The estimated cost, with the tunnel, was fixed at \$25,000,000, though, if an open cut were substituted for the tunnel by raising the cut to elevation 275 feet above sea level, the estimated cost was placed at \$28,000,000. This report was a disappointment to the projectors; the French government would furnish no assistance, and the concession was forfeited.

The settlement of the Northwestern boundary question, by which the United States came into possession of Oregon, and the termination of the Mexican War, by which California was added to the Union, followed by the discovery of gold in the territory recently acquired, brought prominently to the attention of the American people the question of transportation via the Isthmus. Communication overland to the Pacific Coast was so difficult and dangerous, that the main current of immigration was via Cape Horn. To make the newly acquired territory more accessible, lines of steamers were inaugurated from New York to the Isthmus, and from the Isthmus to California and Oregon, but the passage across the Isthmus was attended with serious personal inconveniences and suffering, as well as exorbitant charges. The importance of making a connection across the Isthmus aroused the Government to action, and arrangements were made for a treaty with New Granada, by which the right of transit across the Isthmus of Panama was secured; the ratifications were exchanged on June 10, 1848.

Before this date, in May, 1847, the Republic of New Granada granted a concession to an association of Frenchmen, represented by Mateo Kline, and known as the Panama Company, the exclusive privilege of building a railroad across the Isthmus, and operating it for 99 years, to be counted from the day of the completion and opening of the road to public use. The

company failed to comply with the terms of its contract, which was declared forfeited.

Subsequent to the exchange of ratifications of the treaty with New Granada, efforts were made to negotiate a treaty with Nicaragua, to secure the rights of transit for the United States and its citizens. By the terms of the convention negotiated by the Charge d'Affaires of the United States, Nicaragua conferred on the United States, or a company of its citizens, the exclusive right to construct through its territory, canals, railways, or any kind of roads, so as to open a passage and communication by land or water, or both, between the Caribbean Sea and the Pacific Ocean. In return, the United States was to aid and protect Nicaragua in all defensive wars to the extent of protecting and preserving its territorial limits. The treaty was not approved in Washington, and the Chargé, who had exceeded his authority, was relieved.

His successor arranged a treaty upon the subject, and a contract with the American, Atlantic, and Pacific Ship Canal Company, composed of Cornelius Vanderbilt, Joseph L. White, Nathaniel Wolfe, and their associates. While the treaty was not ratified, the contract was protected by the company securing articles of incorporation from Nicaragua. By the terms of the contract, the company had the exclusive right of excavating a ship canal for vessels of all sizes from Greytown to any point on the Pacific, by means of the San Juan River, Lake Nicaragua, the Tipitapa River and Lake Nicaragua, or any other waters within its jurisdiction. It also gave exclusive right for the construction of rail or carriage roads, or both.

The company determined that there should be a careful instrumental survey made from ocean to ocean, and that a line of location should be determined. Colonel Orville W. Childs, of Philadelphia, was appointed chief engineer, and took charge of the work in August, 1850, and completed it in March, 1852.

Colonel Childs, after the completion of his surveys, reached the conclusion that a ship canal by the Nicaragua route was practicable only by following up the valley of the San Juan River to Lake Nicaragua, and from that lake either southwesterly along a line through some valley extending across the dividing ridge, or northwesterly up the River Tipitapa to Lake

Managua, thence through the valley extending through the head of that lake to some suitable seaport on the Pacific; as between these two routes, an examination led him to believe that the one leading from the lake at the mouth of the River Lajas, up the eastern slope of the divide, and down the valley of the Rio Grande on the western slope to the Pacific, presented more favorable conditions than any other between Lake Nicaragua and the Pacific, and was superior to any route by way of Lake Managua. His project has been the basis for all subsequent ones.

At the request of the company, President Fillmore submitted Colonel Childs' report of the survey and location to Colonel J. J. Abert and Lieut.-Col. W. Turnbull, United States Topographical Engineers, for their inspection and opinion, and they reported in March, 1852, that the plan proposed was practicable, but recommended some changes and modifications. Nothing further was done by the American, Atlantic, and Pacific Ship Canal Company toward the construction of a maritime canal, and its contract was forfeited.

In December, 1848, an exclusive concession was granted by New Granada to William H. Aspinwall, John L. Stephens, and Henry Chauncey, for the construction of roads, railroads, or a canal across the Isthmus of Panama, in other respects somewhat similar in its provisions to the Kline concession. The Panama Railroad Company was organized under the laws of New York, and construction was begun in 1850. After coping successfully with various financial and physical difficulties, the road was opened from Aspinwall (now Colon), to Panama, in 1855. While this made the passage of the Isthmus easier, it did not abate the desire for a canal, and explorations were made for developing the possibilities of the various routes that had been proposed from time to time. No less than nineteen different routes had been suggested and received more or less attention. Of these, the Tehuantepec, Nicaragua, Panama, and Darien projects were the most important, and the Nicaragua route was the principal rival of that via Panama for over thirty years.

With the construction of the Panama Railroad, its concession was respected, and the subsequent investigations extended

from Panama to the Atrato River, three general lines being examined—the San Blas, the Caledonia Bay and Atrato routes.

In 1869 General Grant became President, and in his first message to Congress he recommended an American canal, on American soil, by the American people. Congress responded promptly to this sentiment, and a resolution was passed providing for further explorations of the Isthmus by officers of the Navy, and Admiral Ammen, Chief of the Bureau of Navigation, organized and sent out expeditions for that purpose. In March, 1872, a further resolution was adopted for the appointment of a commission, to consider the results of the explorations and to obtain from other reliable sources all of the available information regarding the practicability of the construction of a canal across the American continent. The President appointed on this interoceanic canal commission, General A. A. Humphreys, Chief of Engineers, U. S. Army, C. P. Patterson, Superintendent of the Coast Survey, and Commodore Daniel Ammen, Chief of the Bureau of Navigation, U. S. Navy. Examinations were made of the Tehuantepec, the Nicaragua, the Panama, the Darien, the Atrato Valley, the San Blas, and the Caledonia routes, and in February, 1876, they unanimously reported in favor of the Nicaragua route, as possessing greater advantages and fewer difficulties, from an engineering, commercial and economic point of view, than any one of the other routes shown to be practicable by the surveys.

While the interoceanic canal commission was examining into the merits of the different canal routes, a geographical congress was held in Antwerp at which an interoceanic canal received much attention, and in 1876 General Turr sent Anthoine Gorgoza to make explorations for a canal. Gorgoza, representing himself as the agent of a French company, secured a hearing before the Colombian Congress, and obtained a concession for a canal by the Atrato route, which he took to Paris. As a result of his representations, a corporation called "La Société Civile Internationale du Canal Interoceanique" was organized, in 1876, for the promotion of a canal on the lower Isthmus, with General Etienne Turr as its president, to make surveys and explorations for a ship canal across the Isthmus of Panama. Count Ferdinand de Lesseps, builder of the Suez

Canal, was also interested in the company, and, on his advice, Lieutenant Wyse went to the Isthmus and explored the Atrato-Tuyra route proposed by Gorgoza, but, finding it impracticable, he decided to report in favor of a modification of it from the Tuyra River to Acanti Bay. The report was not satisfactory to de Lesseps, who urged Lieutenant Wyse to return for further exploration, which he did in 1877, accompanied by Lieutenant Armand Raclus. They first examined the San Blas route, and finding it more impracticable than Wyse's route, they proceeded to Panama. Raclus undertook the survey of the route, while Wyse went to Bogota and secured a concession for a canal anywhere on the Isthmus, provided he or his company could make satisfactory arrangements with the Panama Railroad Company, which was subsequently accomplished. It was also stipulated in the concession that the route of the canal should be determined by an international commission of individuals and competent engineers.

Wyse and Raclus returned to Paris in 1878 and made a favorable report on the Panama route to the Société Civile. Under the presidency of M. de Lesseps, a "Congrès International d'Etudes de Canal Interoceanique" was invited to assemble in Paris in 1879, to consider and pass definitely upon the whole question. This congress consisted of 135 delegates, and was composed of lawyers, bankers, promoters, and scientists, most of them favorably disposed toward M. de Lesseps, who had attained such success at the Suez Canal. The route proposed by the plans prepared by Wyse and Raclus contemplated a sea level canal 28 feet deep and a ruling bottom width of 72 feet. Leaving Colon, the canal passed through low ground to the valley of the Chagres at Gatun, a distance of about six miles; thence through this valley for 21 miles to the mouth of the Obispo, where, leaving the Chagres, it followed the valley of the Obispo, passed through the continental divide at Culebra by means of a tunnel, and reached the Pacific through the valley of the Rio Grande. The difference in tides of the two oceans was to be overcome by the proper sloping of the bottom of the Pacific portion of the canal.

The congress was divided into five large committees, to consider, (1) Statistics; (2) Economic and commercial ques-

tions; (3) Navigation; (4) Technical questions; and (5) Ways and means. The technical committee discussed the plans of the canal, and apparently the discussions were long and sometimes heated. M. de Lesseps, for some time before the meeting of the congress, advocated a sea level canal, would listen to nothing else, and opposition to his views was manifested mainly by abstaining from voting. Thus, at the time of formulating the opinion of the technical committee, forty members absented themselves, ten refrained from voting, and only nineteen voted, sixteen of whom favored the sea level canal. The decision was: "that the route of the interoceanic canal should be from the Gulf of Limon to the Bay of Panama, and particularly recommends the construction of a ship canal at sea level in that direction". When the question was decided by the congress, thirty-seven members were absent, ten abstained from voting, and there were 78 ayes and 8 noes for the sea level plan.

It is interesting to note that a plan submitted to the technical committee by Godin de Lepinay proposed a dam across the valley of the Chagres at Gatun, thereby creating an interior lake of sufficient height to absorb the waters of the Chagres, the difference in level being overcome by a flight of five locks on either side, with an additional lock on the Pacific side because of the tidal variations. The level of the lake was to be "a little below the height of the highest waters, and we get rid of the Chagres, whose presence near the trenches constitutes an increase of expense and a considerable augmentation of the time required for the work." This project would reduce very materially the amount of excavation, which was regarded not only as the greatest difficulty, but also the greatest danger to health, with respect to which it was noted that "it is very dangerous to the health of the men employed in the works to dig up the earth". The cost both in time and money was also less. Those who favored this plan advocated strongly its adoption, because "it is, we repeat, the most natural method, because it does away with the labor and with the unhealthiness of the soil, and because it is most advantageous to navigation".

The estimate proposed for the sea level canal was $240,000,000 and completion in twelve years' time. While these were considered low by the members of the technical committee,

M. de Lesseps considered them too high, and expressed himself as fully convinced that with a good and judicious organization the work could be finished for $131,600,000 and within eight years' time.

As a result of the International Congress, "La Compagnie Universelle du Canal Interoceanique de Panama", known in the United States as the Panama Canal Company, was organized in 1881, with Ferdinand de Lesseps at its head, to construct a sea level canal along the proposed route. The plan was modified by an open cut in lieu of a tunnel through the continental divide, and a tidal lock on the Pacific slope. Various schemes were proposed for the control of the Chagres, the most promising being the construction of a dam at Gamboa and the excavation of independent channels to the sea. The dam was decided subsequently to be impracticable, and the problem remained unsolved.

The concession secured by Lieutenant Wyse was purchased by the company, and the construction of a canal was begun. The work, as it was carried forward, was not commensurate with completion in eight years' time, and in 1885 and in 1886 the engineers pointed out the difficulties of the situation, and proposed solutions that could be accomplished more speedily and at less expense. Public suspicion had been aroused; money was difficult to procure; consequently it was necessary to make an effort to restore the confidence of the public.

In his report to the stockholders of the company in 1887, M. de Lesseps announced the intention to seek a more speedy solution, such as would make it possible, without abandoning the plan of a canal at sea level, to open a temporary one for operation at the appointed time. In the latter part of that year a temporary canal, with locks, was adopted, to be opened in 1891. The line followed the route that had already been accepted, and a summit level was fixed at 159 feet above the sea, to be supplied with water from the Chagres by means of pumps. These changes did not restore sufficient confidence to obtain the necessary finances, and legislation was secured for the issue of lottery bonds. This method of financing the scheme was not successful, and the company passed into the hands of a receiver in February, 1889.

While arrangements were making for the Panama Canal by the French Company, Mr. James B. Eads, in 1881, endeavored to carry out his project for a ship railway by the Tehuantepec route, and obtained a charter from Mexico for its construction. An effort was made to secure Congressional aid, but without success.

In December of 1884 a treaty was negotiated between the United States and Nicaragua, for the construction of a canal by the former, to be owned by the two contracting parties. While the treaty was pending in the Senate in 1885, it was withdrawn by the President for the reason that the perpetual alliance with Nicaragua which the treaty proposed, as well as the protection of the integrity of the territory of that state, was contrary to the policy of the United States.

In 1887, Nicaragua granted a concession to Mr. A. G. Menocal and others, for the construction of a ship canal from Greytown to Brito, and, as the canal would affect the territory of Costa Rica also, a like concession was secured from this republic in 1888. The Maritime Canal Company of Nicaragua was organized and incorporated by the Congress in 1889, for the construction of the canal. Actual construction was begun in October of 1889 and was continued for over three years, but comparatively little was accomplished. Work was suspended during 1893. Several attempts were made to secure Government aid, but without success. While a bill for this purpose, after its passage by the Senate in 1895, was pending in the House of Representatives, where it subsequently failed, an amendment was made to the Sundry Civil Bill which provided for a board of three officers, one from the Army, one from the Navy, and one from civil life, to make a personal investigation, and to examine the "plans, profiles, sections, prisms and specifications" for the various parts of Menocal's plans for the Nicaragua canal, for the purpose of ascertaining "the feasibility, permanence, and cost of construction and completion of the canal". The board appointed consisted of Lieutenant-Colonel William Ludlow, Corps of Engineers, U. S. Army, Civil Engineer M. T. Endicott, U. S. Navy, and Alfred Noble, Civil Engineer. The board found it impracticable, within the time fixed by law and with the limited means appropriated for its work,

to make a full and thorough examination of the route and obtain the necessary data for a final project, and recommended that further explorations be undertaken and observations made, to collect the information and data necessary for the canal project, so as to determine the final location and cost of the work. The board submitted, however, a tentative estimate of cost.

After the failure of the Panama Canal Company steps were taken to reorganize, with a view to carrying forward the work, but, as the original concession had nearly expired, application was made to secure its renewal, and an extension of ten years from April 4, 1893, was granted, which later was extended to October 31, 1910. The company called to its assistance a technical committee composed of fourteen engineers, European and American, to study all the data available, which recommended the lock type of canal composed of three levels, one of them an artificial lake to be created by a dam at Bohio, to be reached from the Atlantic by a flight of two locks, and another a summit level, to be reached by a second flight of two locks. The bottom of the summit level was to be 68 feet above the sea, supplied with water by a feeder leading from an artificial reservoir created by a dam to be constructed at Alhajuela. The ascent on the Pacific side was to be by four locks, of which the two middle ones were combined in a flight. The canal was to have a depth of 29½ feet and a bottom width of not less than 98 feet. A second plan was submitted (a modification of the first by the omission of the upper level), but this was not advocated or accepted, because of the additional time that would be required for the construction, which it was deemed desirable to avoid.

Carrying out the recommendations of the board organized under the Sundry Civil Act of 1895, Congress appropriated by the Act of June 4, 1897, funds to "continue the surveys and examinations authorized by the Act approved March 2, 1895, into the proper route, feasibility, and cost of construction of the Nicaragua canal, with a view to making complete plans for the entire work of construction of such canal as therein provided". The President appointed Admiral John G. Walker, U. S. Navy, Captain Oberlin M. Carter, Corps of Engineers, U. S. Army, whom he replaced on October 18 by Colonel Peter

C. Hains, Corps of Engineers, U. S. Army, and Professor Lewis M. Haupt, to constitute the commission required by the law. This board submitted its report in May, 1899, with the necessary detailed data and estimates for the construction of the Nicaragua canal.

Both of these commissions were appointed for the purpose of examining into the Nicaragua route only, but, prior to the submission of its report by this later commission, the Act of March 3, 1899, authorized the President to make a full and complete investigation of the Isthmus of Panama, with a view to the construction of a canal, as well as to make investigation of any and all practicable routes for a canal across the Isthmus of Panama, investigating particularly the Nicaragua route and the Panama route with a view to determining the most practicable and feasible route for a canal connecting the Atlantic and Pacific Oceans, together with the approximate and probable cost of construction of a canal by each of the two or more said routes.

In compliance with this Act the President appointed Admiral J. G. Walker, U. S. Navy, Samuel Pasco, Alfred Noble, Geo. S. Morison, Colonel Peter C. Hains, Corps of Engineers, U. S. Army, Professor Wm. H. Burr, Lieutenant-Colonel O. H. Ernst, Corps of Engineers, U. S. Army, Professor Lewis M. Haupt, and Emory R. Johnson, as a commission to carry out the wishes of the Congress as expressed by the Act. This board submitted its report on November 16, 1901. With regard to the choice of routes, the board reported: "There are certain physical advantages, such as shorter canal line, a more complete knowledge of the country through which it passes, a lower cost of maintenance and operation, in favor of the Panama route, but the price fixed by the Panama Canal Company for a sale of its property and franchises is so unreasonable that its acceptance cannot be recommended by this commission. After considering all the facts developed by the investigations made by the commission, and having in view the terms offered by the New Panama Canal Company, this commission is of the opinion that 'the most practicable and feasible route' for an Isthmian canal to be 'under the control, management and ownership of the United States', is that known as the Nicaragua route".

In arriving at this conclusion the price fixed by the New Panama Canal Company was $109,141,500. The board was of the opinion that the value of the French property to the United States was $40,000,000, and had this figure been acceptable the report leaves no doubt that the recommendation of the board would have been different. Because of lack of funds the New Panama Canal Company could not carry the work to completion, and their only hope for any return for the investment was from the United States; under these circumstances, the company, on January 4, 1902, declared itself ready to transfer to the United States its properties and concessions on the payment of $40,000,000. This put a new phase on the situation, and the Isthmian Canal Commission was called together, changed its previous recommendation, and on January 18, 1902, reported that "conditions that now exist and all the facts and circumstances upon which its present judgment must be based, the commission is of the opinion that 'the most practicable and feasible route' for an Isthmian canal, to be under 'the control and management and ownership of the United States', is that known as the Panama route".

The plan adopted by the Isthmian Canal Commission of 1899-1901 for the Panama route was for a summit-level canal. The report sets forth that the control of the Chagres was the greatest natural difficulty to be encountered, and "if a sea level canal be constructed, either the canal itself must be made of such dimensions that maximum floods, modified to some extent by a reservoir in the upper Chagres, could pass down its channel without injury, or independent channels must be provided to carry off these floods. . . . While such a plan would be physically practicable, and might be adopted if no other solution were available, the difficulties of all kinds, and especially those of time and cost, would be so great that a canal with a summit level reached by locks is to be preferred". The summit level was to be created by a dam at Bohio which would form a lake, the normal elevation of which was fixed at 85 feet above sea level, but fluctuating between 82 and 90 feet, and regulated by a spillway 2000 feet wide near the headwaters of the Rio Gigante, a tributary of the Chagres. The difference of level was to be overcome by a flight of two locks at Bohio, with

a total lift of 82 feet, at the minimum level of the lake, to 90 feet at the maximum. On the Pacific slope a flight of two locks was placed at Pedro Miguel, with a lift varying from 54 to 62 feet, and a lock at Miraflores, with a lift varying from 8 feet at high tide to 38 feet at mean low tide. The locks were in duplicate, 740 feet long in the clear, 84 feet wide, and 35 feet deep. The ruling bottom width of the canal was 150 feet, and for purposes of estimates the side slopes were 3 to 1, except in Culebra Cut, where the slopes were 1 on 1; the minimum depth of 35 feet was adopted for the canal. The entrance channel from the six-fathom curve in Limon Bay to Cristobal Point had a width of 500 feet, while, from the Panama Railroad pier at La Boca to deep water in the Pacific, the channel width was fixed at 200 feet. It will be noted that these proposed plans followed closely the second project considered by the New Panama Canal Company. The estimated cost of the canal was $144,233,358, exclusive of the cost of the French property.

By an Act of Congress approved June 28, 1902, commonly known as the Spooner Act, the President was authorized to acquire, at a cost not to exceed $40,000,000, the rights, privileges, franchises, concessions, and other property owned by the New Panama Canal Company, and to secure from the Republic of Colombia, upon such terms as he might deem reasonable, the perpetual control of a strip of land, not less than six miles in width, across the Isthmus between the seas, with the right to maintain and operate perpetually the Panama Railroad Company, should the United States acquire the ownership or controlling interest. Assuming that satisfactory arrangements could be made with the Republic of Colombia, and that the property of the New Panama Canal Company could be purchased at the price mentioned, the President was then authorized to construct a canal, which was to be of sufficient capacity and depth for vessels of the largest tonnage and the greatest draft in use or that might be reasonably anticipated. Should the President be unable to obtain a satisfactory title to the New Panama Canal Company's property, or secure the necessary territorial control from the Republic of Colombia, within a reasonable time and at a reasonable cost, then he should endeavor to secure such control and jurisdiction from Costa

Rica and Nicaragua, and construct the canal by the Nicaragua route.

A satisfactory treaty for the accomplishment of the purposes mentioned in the Act was arranged between the governmental authorities of the United States and Colombia, but subsequently failed of ratification by the legislative body of Colombia. The secession of the Province of Panama and the establishment of an independent Republic followed. The independence of the new Republic was recognized by the United States, and a treaty was made by which the United States obtained the control and jurisdiction over a strip of land ten miles wide, measured five miles on either side of the center line of the proposed canal across the Isthmus of Panama. The French property was purchased for the sum stipulated, including a controlling interest in the Panama Railroad, which by the terms of the treaty passed to the control of the United States.

In considering the legislation under which the construction of a canal was authorized, and the amount of the bond issue, there is no doubt that the canal was to be in accord with the plans submitted by the Commission of 1899-1901; yet, shortly after the United States took possession on May 8, 1904, the question of a sea level versus a lock canal was agitated, and took such a hold upon the public imagination that the President convened a board of engineers to consider the entire subject. This board consisted of General George W. Davis, Alfred Noble, William Barclay Parsons, William H. Burr, General Henry L. Abbot, Frederick P. Stearns, Joseph Ripley, Isham Randolph, William Henry Hunter (nominated by the British Government), Eugen Tincauzer (nominated by the German Government), Adolph Guerard (nominated by the French Government), E. Quellenac (consulting engineer of the Suez Canal), and J. W. Welcker (nominated by the Government of the Netherlands). The board submitted its report on February 5, 1906; a majority, eight in number, favored the sea level canal, and a minority, five in number (Alfred Noble, General Henry L. Abbot, Frederick P. Stearns, Joseph Ripley and Isham Randolph) favored the lock type of canal.

The advocates of the sea level project proposed to control the Chagres River by means of a dam at Gamboa, the floods to

escape through sluiceways constructed in the bottom of the dam, and at such a rate as not to make objectionable currents in the canal. A tidal lock, 1000 feet in length in the clear, and 100 feet wide, at Sosa Hill, in the vicinity of the Pacific entrance, was to be constructed. The depth of water in the canal was fixed at 40 feet, with a bottom width varying from 150 feet in earth or soft material to 200 feet through rock. Through the continental divide the sides of the canal were to have slopes of 10 on 1 to 10 feet above sea level, with berms of 45 feet on either side, then slopes of 3 on 2 to the top of the cutting.

The plan for the lock type proposed the creation of interior lakes by dams across the Chagres River valley at Gatun and the Rio Grande valley on the Pacific side. In the former case, the normal level of the lake was fixed at 85 feet above sea level, while the lake created by the dams on the Pacific side would be held at 55 feet above the sea. The enormous summit lake, 164 square miles in area, would absorb the floods of the Chagres and its tributaries, and regulation was secured by means of a spillway constructed nearly midway the length of the dam, capable of discharging the maximum floods that were liable to occur. A channel of 500 feet bottom width extended from Limon Bay to Gatun, with a depth of 41 feet at mean tide (tidal variation 2 feet), where a flight of three locks overcame the difference of level between the lake and the sea. The channel through the continental divide, or Culebra Cut, was given a bottom width of 200 feet.

On the Pacific side, one lock was placed at Pedro Miguel with a lift of 30 feet, and the dams on the Pacific side extended from Sosa to Corozal, from Sosa to San Juan Hills, and from Corozal to Diablo Hill. Descent to the Pacific was made by a flight of two locks; from these locks to deep water in the Pacific was a dredged channel of 500 feet bottom width, with a depth of 45 feet at mean tide (variation 20 feet).

Between Gatun and Pedro Miguel locks the minimum depth was 45 feet, with bottom widths of channel, starting from Gatun locks, of 1000 feet for 15.69 miles, 800 feet for a distance of 3.86 miles, 500 feet for 3.75 miles, 300 feet for 1.55 miles, and 200 feet through the central mass called Culebra, broadening out again to 300 feet for 1.88 miles north of Pedro

Miguel; after passing through the locks at this locality the channel was fixed at 500 feet bottom width for 1.64 miles, increasing to 1,000 feet for the remaining distance of 3.38 miles to the Sosa locks. The dimensions of the locks were fixed at a usable length of 900 feet, width 95 feet, and depth on the mitre sills of 40 feet. Breakwaters nearly parallel with the channel were projected, for protecting the channel through Limon Bay against storms.

Gatun dam as projected was 7,700 feet long, 2,625 feet wide at the bottom, 100 feet wide at the top, and 374 feet thick at the normal lake level. The side slopes were to be 1 on 3 up to elevation 90 on the upstream side, then 1 on 2 to elevation 135; on the downstream side, 1 on 2 from elevation 135 to 88, 1 on 25 from elevation 88 to 20, and 1 on 50 for the rest of the slope.

Advantage was taken of a hill, the top of which was at reference 110, for the construction of a spillway. The spillway dam was to be of concrete with crest at elevation 69, and gates operating between piers built 38 feet centers, the clear openings being 30 feet. The crest of the spillway dam was a straight line, and the openings capable of discharging 140,000 second feet.

The creation of the lakes practically required the reconstruction of the Panama Railroad for nearly its entire length.

Those advocating the lock type of canal advanced the following reasons for its selection:

1. Quicker passage for traffic than would be afforded by the narrow waterway of a sea level canal;

2. Greater safety for vessels and less danger of interruption of traffic by reason of the wider and deeper channels which the lock canal makes possible at small cost;

3. Quicker passage across the Isthmus for large ships or large traffic;

4. Materially less time required for construction;

5. Materially less cost.

These are practically the same reasons that were advanced by Godin de Lipinay in 1879 when he proposed this type of lock canal before the International Congress held in Paris.

The principal objections to the lock type of canal were the

alleged experimental nature of hydraulic filled dams, their probable instability due to the character of the foundations, and the great danger to the canal resulting from damage to the locks.

The report of the board was submitted first to Mr. John F. Stevens, Chief Engineer of the Isthmian Canal Commission, who had, in advance of the report of the consulting board, expressed himself in favor of a high-level canal. He recommended the adoption of the type proposed by the minority of the board, modified by the withdrawal of the locks located at Sosa Hill, on the grounds of the unsanitary conditions that would be created by a lake in the vicinity of Panama, and the exposure of these locks to attack or destruction in the event of war. The members of the Isthmian Canal Commission, with one exception, advocated the adoption of the lock type of canal. This in turn was recommended by the Secretary of War to the President, who transmitted a report to Congress advocating the adoption of the lock type. After considerable discussion, the Congress expressed itself in favor of the lock type, on June 29, 1906.

This did not put an end to the discussion, nor the attacks on the dams and the foundations for the Gatun locks; the latter were passed upon as sufficient for the purpose in April, 1907, by a board consisting of Alfred Noble, Frederick P. Stearns, and John R. Freeman. In 1908, a slip occurred in a rock pile which formed part of the Gatun dam, and revived the question of the sea level versus the lock type of canal. A rock pile was being constructed to elevation 60 on the upstream side, to form the south toe of the dam, and was being carried across the old French canal, when, because of the steepness of the slope on the downstream side and the amount of silt and soft material in the canal, a movement downstream occurred, carrying with it part of the downstream side of the rock pile. Occurring at a time of flood in the Chagres River, the facts were distorted and exaggerated in the public press, and the slip was attributed to the breaking through of the mass into a "subterranean lake" discovered by a newspaper correspondent then on the Isthmus. The whole question was gone over again early in 1909 by a board of engineers appointed by the President for the purpose

of determining whether or not a change in plans should be made. The board consisted of Frederick P. Stearns, Arthur P. Davis, Henry A. Allen, James D. Schuyler, Isham Randolph, John R. Freeman, and Allen Hazen. Notwithstanding the stress that was laid upon the assertion that the water of the lake would seep through the hills; that the seamy character of the rock permitted the passage of water through Spillway hill and elsewhere; that the underground flow from the adjacent hills under the Gatun locks would undermine these or make their construction difficult if not doubtful; and that the swampy condition of a part of the site of the dam made the building of this structure uncertain; this board recommended adherence to the original project.

By Executive Order the dimensions of the locks were changed to a length in the clear of 1,000 feet and a width of 100 feet. These dimensions were criticised in the public press and by officers of the Navy. As the canal was for naval use it was thought that the Navy Department should pass upon the question, and to enable them to arrive at a conclusion, estimates were prepared showing the cost for each increase in width of 5 feet up to 125 feet, and the views of the Navy requested as to the width that should be adopted. In a memorandum dated October 29, 1907, the President of the General Board of the Navy submitted a memorandum stating it was their opinion that sound policy would dictate an increase to a clear width of 110 feet; that the length of the locks as then planned—1,000 feet—was deemed to be sufficient for all naval purposes for an indefinite time to come; consequently, the width of 110 feet was adopted.

In recommending the lock type of canal to President Roosevelt, the Secretary of War, Mr. Taft, called attention to the exposed location of the locks on the Pacific side to hostile fire in case of war, and recommended their withdrawal, if practicable. Agua Dulce had been proposed, and offered the best site, but explorations of the foundations developed no suitable rock of sufficient extent, and the only location where rock was found for the purpose was at Miraflores. On recommendation of the Isthmian Canal Commission the Sosa Hill site with its adjacent dams was abandoned. At the time this change was

adopted, the question of concentrating all the locks on the Pacific side in a flight at Miraflores was brought up and considered, but the plan was not adopted because of the extent and character of the foundations which were the poorest under any of the structures on the Isthmus, the great depth to rock for part of the structures which imposed too great pressures, and the question of water supply; economy in the use of water resulted from the separation of the locks at Pedro Miguel and Miraflores. A better arrangement would have been secured by two locks at Pedro Miguel and one at Miraflores, but again the extent of suitable foundations at Pedro Miguel would not permit.

The direction of the breakwaters was changed. These were intended to protect the channel as well as the harbor against the "northers" that occur on the Atlantic coast, and to give a place of shelter and refuge for shipping. Breakwaters built practically parallel to the channel gave an area but little greater than the channel, in which waves could dissipate after their entrance between the breakwaters, so they could not accomplish the purpose for which they were intended. The west breakwater was projected from Toro Point, and the second one, should experience indicate the necessity for it, was planned on the east side of the entrance running out from Coco Solo. The east breakwater is now building at the request of the General Board of the Navy.

In 1908, the President, by Executive Order, increased the bottom width of the canal through Culebra Cut to 300 feet. The channel just north of Pedro Miguel was increased to 600 feet in width for a distance of 1,050 feet, gradually reducing to 300 feet in the next 1,600 feet, to provide for the draw that results from filling the locks.

In addition to the changes in the proposed project already noted, modifications were made in the plans for the dam at Gatun. The slopes were flattened to 1 on 7.67 on the upstream side to conform to what experience with the embankments of the new Panama Railroad showed to be necessary, and 1 on 12 on the downstream side. The dam was made 2,180 feet wide at sea level, 390 feet wide at the 85-foot level, and the crest built to elevation 105. The plan for the spillway was changed also;

the crest was curved, and the size of the openings increased, though the same rate of discharge as originally proposed was maintained. Minor modifications were made in the alignment of the canal south of Bohio, but on the whole the sailing lines originally adopted were retained. The sailing line could have been shortened by cutting through Bohio ridge, but until commerce through the canal indicates its necessity the time saved would not warrant the expenditure required to make the change.

The Panama Railroad was relocated practically throughout its entire length. As projected, it was to follow the 95-foot level through Culebra Cut on a berm left for the purpose during construction, but the slides forced the construction of the road over the continental divide east of Gold Hill where an elevation of 271 feet is reached.

On the south, the summit level of the canal is maintained by means of Pedro Miguel Locks, an earth dam extending from the west lock wall to the adjacent hill, and a masonry cutoff built from the east side of the locks into the rock of the adjacent hill. The Pedro Miguel dam is of earth, 2,000 feet long, with a concrete core wall tying it to the adjacent hill and across the bed of the Rio Grande. It is 1,000 feet wide at the base (elevation 55), 730 feet wide at the 85-foot level, and the top is at elevation 105. The cutoff wall on the east is built on rock, and the top is at reference 92.

Miraflores lake is sustained by a dam, the locks and a spillway dam. The spillway is capable of discharging 90,000 second feet, and is constructed with a cross section similar to that of Gatun spillway, the crest of the dam being straight instead of curved, and at elevation 38.87, or 16 feet below the normal level of Miraflores Lake. A water cushion on the downstream side breaks the force of the water on its descent. The west dam is of earth extending from the head of the locks to Cocoli Hill almost at the foot of the locks, thus throwing the waters of the Cocoli River into the lake; the dam is nearly parallel to the locks. It is hydraulic filled, from 940 to 1,050 feet wide at elevation 55, and its crest is at elevation 70. Concrete core walls were constructed to tie it to Cocoli Hill and across the bed of the river.

A breakwater is built in extension of Balboa dumps south of Sosa Hill, formed of waste material from Culebra Cut, out to Naos Island, as the channel was changed from north of the island to the west. The breakwater was intended to protect the channel against filling by the littoral drift, which is from east to west.

The estimate prepared by the Minority of the Board of Consulting Engineers for the construction of the proposed 85-foot summit level canal was $139,705,200, exclusive of interest during construction, sanitation, or expenses of civil administration, as well as moneys paid to the Republic of Panama and the French Canal Company. It was apparent in 1907 that the estimates were too low. Wages and salaries were much in excess of those paid for similar employment in the United States; the expense for quarters erected for employees and their families, the leave privilege with pay, and other conditions of employment, made the cost higher, particularly the substitution of an eight-hour day for the ten-hour day estimated in 1906; an era of prosperity in the United States had increased the cost of materials of all kinds; and, finally, the enlargement of the channel through Culebra Cut and the increased dimensions of the locks, materially increased the quantities. The estimates as revised included all moneys paid out in connection with the canal, including $10,000,000 paid to Panama and $40,000,000 paid for the property rights of the New Panama Canal Company, advances made to the Panama Railroad Company, the purchase of the outstanding stocks and bonds of this company, the cost of constructing the canal, sanitation, and civil administration. The total amount aggregated $375,201,000.

In 1910, when it became apparent that the available balance would permit the construction of dry docks, machine shops, and coaling stations, these were advocated as adjuncts to the canal, but, as they were not authorized by Congress until the latter part of August, 1912, they are completed only in part.

The Minority of the Board of Consulting Engineers estimated that nine years would be required to complete the summit-level canal, or to January 1, 1915; this date was accepted, and the work adjusted and prosecuted to this end. The result was

that the work in all its parts was advanced to such a stage that the first ocean steamer was passed through the canal on August 3, 1914, and, but for the unexpected slide which occurred north of Gold Hill on October 14, 1914, the canal would have been completed in its entirety within the estimated time.

STATISTICS.

Length from deep water to deep water (miles)	50
Length from shore line to shore line (miles)	40
Bottom width of channel, maximum (feet)	1,000
Bottom width of channel, minimum, 9 miles, in Culebra Cut (feet)	300
Locks, in pairs	12
Locks, usable length (feet)	1,000
Locks, usable width (feet)	110
Gatun Lake, area (square miles)	164
Gatun Lake, channel depth (feet)	85 to 45
Culebra Cut, channel depth (feet)	45
Excavation, due to slides and breaks, estimated (cubic yards) (about)	25,000,000
Excavation accomplished to March 31, 1915 (cubic yards)	232,440,945
Excavation remaining, Canal proper, March 31, 1915, estimated (cubic yards)	6,404,642
Excavation by the French (cubic yards)	78,146,960
Excavation by French, useful to present Canal (cu. yards)	29,908,000
Excavation by French, estimated value to Canal	$ 25,389,240
Value of all French property	$ 42,799,826
Concrete, total for Canal, excluding terminals (cubic yards)	4,844,566
Time of transit through completed Canal (hours)	10 to 12
Time of passage through locks (hours)	3
Relocated Panama Railroad, total cost	$ 8,866,392
Relocated Panama Railroad, length (miles)	47.11
Canal Zone, area (square miles)	436
Canal and Panama Railroad force actually at work in September, 1913 (about)	37,000
Canal and Panama Railroad force, Americans in September, 1913 (about)	5,000
Cost of Canal, estimated total	$375,000,000
Work begun by Americans	May 4, 1904

CANAL APPROPRIATIONS.

Payment to New Panama Canal Company	$ 40,000,000.00
Payment to Republic of Panama	10,000,000.00
Appropriation, June 28, 1902	10,000,000.00
Appropriation, December 21, 1905	11,000,000.00

Deficiency, February 27, 1906	5,990,786.00
Appropriation, June 30, 1906	25,456,415.08
Appropriation, March 4, 1907	27,161,367.50
Deficiency, February 15, 1908	12,178,900.00
Appropriation, May 27, 1908	29,187,000.00
Deficiency, March 4, 1909	5,458,000.00
Appropriation, March 4, 1909	33,638,000.00
Deficiency, February 25, 1910	76,000.00
Appropriation, June 25, 1910	37,855,000.00
Appropriation, March 4, 1911	45,560,000.00
Appropriation, August 24, 1912	28,980,000.00
Appropriation, June 23, 1913	16,265,393.00
Deficiency, April 6, 1914	2,450,000.00
Private Act, Relief of Elizabeth G. Martin	1,200.00
Private Act, Relief of Marcellus Troxell	1,500.00
Private Act, Relief of W. L. Miles	1,704.18
Private Act, Relief of Chas. A. Caswell	1,056.00
Private Act, Relief of Alexandro Comba	500.00
Private Act, Relief of Douglas B. Thompson	1,500.00
Private Act, Relief of Robert S. Gill	2,520.00
Private Act, Relief of Peter Wigginton	500.00
Private Act, Relief of Raymond R. Ridenour	500.00
Private Act, Relief of heirs of Charles E. Stump	1,500.00
Private Act, Relief of parents of Edward Maher	1,980.00
Private Act, Relief of Oscar F. Lackey	1,500.00
Private Act, Relief of Pedro Sanchez	2,000.00
Private Act, Relief of John H. Cole	1,951.38
Private Act, Relief of Robert Coggan	1,500.00
Judgment, Court of Claims, Timothy J. Butler	196.45
Judgment, Court of Claims, March 4, 1913, The Laidlaw-Dunn Gordon Company	900.00
Total	$341,279,369.59
Appropriation for Fortifications, March 4, 1911	3,000,000.00
Appropriation for Fortifications, August 24, 1912	2,806,950.00
Appropriation for Fortifications, June 23, 1913	4,870,000.00
Deficiency, April 6, 1914, Fortifications	249,350.00
Grand total	$352,205,669.59

CLASSIFIED EXPENDITURES TO JUNE 30, 1914.

Department of Construction and Engineering	$210,159,139.20
Department of Construction and Engineering, Plant	1,135,932.14
Department of Sanitation	17,259,797.30
Department of Civil Administration	7,155,839.98

Department of Law	61,564.55
Panama Railroad, Second Main Track	1,123,522.22
Panama Railroad, Relocated Line	9,271,179.40
Purchase and Repair of Steamers	2,680,112.01
Zone Waterworks and Sewers	6,892,749.44
Zone Roadways	1,704,424.24
Loans to Panama Railroad Company	3,247,332.11
Construction and Repair of Buildings	10,395,318.02
Purchase from New Panama Canal Company	40,000,000.00
Payment to Republic of Panama	10,000,000.00
Miscellaneous	5,059,625.94
Total	$326,146,536.55
Expenditures for Fortifications to July 31, 1914	6,793,089.73

Paper No. 2

COMMERCIAL AND TRADE ASPECTS OF THE PANAMA CANAL.

By

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Special Commissioner on Panama Canal Traffic and Tolls, 1911-13
Philadelphia, Pa., U. S. A.

A discussion of the commercial and trade aspects of the Panama Canal within the limits of a paper of moderate length must necessarily deal briefly with only the more important phases of the subject. In requesting this paper, the chairman of the International Engineering Congress stated that

"While the other papers to be included in this volume [upon the Panama Canal] relate wholly to technical engineering subjects, we feel that the volume as a whole would be quite incomplete without a presentation of the general subject of the economic and commercial significance of the canal, written from a broad standpoint and intended to round out for the technical reader the real significance of the canal as a development in ways and means for expediting the world's commerce".

Until the Panama Canal was opened, commerce between the north Atlantic and Pacific, including the traffic between the two seaboards of the United States, had either to move 3,000 to 3,500 miles by rail across the continent of North America, or be handled via the Isthmus of Tehuantepec or the Isthmus of Panama, or be sent by an all-water route around the continent of South America. The shipments by rail, because of the distance and mountain grades, were and are necessarily expensive. Traffic carried on by way of the Isthmus had to bear the expenses of two shipments by water and of double handling and rail transportation at the Isthmus, while goods shipped by all-water routes through the Straits of Magellan were carried from 13,000 to 15,000 miles. To avoid the long circuitous water route

between the north Atlantic and Pacific by way of the Straits of Magellan, traffic has been transported across the Isthmus of Panama since the opening of the trans-isthmian railroad in 1855; and, from 1907 until the opening of the Panama Canal, an increasing tonnage was transferred across the Isthmus of Tehuantepec by means of the Mexican National Railway. This double handling and rail transportation of traffic at Tehuantepec and at Panama cost from $3 to $3.50 per ton of cargo, and was objectionable not only because of the expense, but because of the risks and delays incident to the double handling of goods in tropical latitudes.

The continent of South America extends to 56° south latitude, and the Straits of Magellan are nearly 54° south of the equator. The South American continent, moreover, not only extends far into southern latitudes but also lies to the east of most of North America. A vessel making a voyage from New York to the Pacific before the opening of the canal was obliged to make 40° of easting in order to round the eastern point of South America and 95° of southing in order to reach the Straits of Magellan. The opening of the Panama Canal enables a vessel from New York to sail almost directly south, and thus to avoid the detour to the east that must be made in reaching the Straits of Magellan. The Isthmus of Panama, moreover, is between 62° and 63° north of the Straits of Magellan.

These broad geographic facts explain how the Panama Canal effects a saving of nearly 8,000 nautical miles in the all-water route between New York and San Francisco, the distance via the canal being 5,262 nautical miles, as contrasted with 13,135 miles by way of the Straits of Magellan. The distance from New Orleans to the canal being less than from New York, and the distance from New Orleans to the Straits of Magellan being greater than from New York to the Straits, the opening of the Panama Canal has reduced the distance between New Orleans and San Francisco nearly 9,000 miles.

REDUCTION EFFECTED BY THE CANAL IN DISTANCES AND SAILING TIME.

The Panama Canal having been constructed primarily to shorten the length and time of ocean voyages, it will be well in

discussing the commercial and trade reasons for the building of the canal to set forth with some detail the effect of the canal upon distances and sailing time by ocean routes between the principal ports of the north Atlantic and the Pacific. While giving primary consideration to the effect of the canal upon the length of routes over which the commerce of the United States is shipped, it will be desirable to point out the effect of the canal upon the distance between Europe and both sides of the Pacific in order to show how the Panama Canal has affected the conditions of competition between Europe and the United States for the trade of the Pacific.

The commerce between the north Atlantic and Pacific is carried on between many ports and by numerous routes. In order to indicate definitely and concisely the effect of the canal upon the length of ocean routes and the time required for voyages, it will be helpful to put the facts in tabular form. The tables here presented are abbreviated from a larger number of more detailed tables contained in the report upon "Panama Canal Traffic and Tolls" which the writer made in 1912 to the Secretary of War. The tables show the saving in distances effected by the Panama Canal for voyages between selected Atlantic and Pacific ports, and give the number of days which vessels of 9, 10, 12, 14 and 16 knots respectively can save in making voyages via the canal instead of by way of routes that were ordinarily followed before the opening of the isthmian waterway. Distances are stated in nautical miles, the length of the Panama Canal being taken at 41 nautical miles, and the Suez Canal at 87 nautical miles. The distances and the saving in time are calculated by routes which include calls at such large ports as vessels regularly visit en route. Where deemed necessary, the ports of call included are indicated in the tables in the column containing "remarks".

The people of the eastern and southern parts of the United States are interested in the Panama Canal, first, because it affords a shorter highway to the west coast of the United States; secondly, because it reduces the distance to the west coast of South America; and, thirdly, because of the opening of a shorter route to Australasia and the Orient. The people of the western section of the United States are benefited by the Panama Canal

because it gives them readier access to the markets of Europe and the eastern part of the United States, while the manufacturers and traders of Europe are benefited by securing a shorter and more direct route to the west coast of the three Americas. Table I sets forth the reduction in distances accomplished by the Panama Canal, as compared with the routes by way of the Straits of Magellan, for voyages from New York and from New Orleans to San Francisco and to selected typical west coast South American ports. The number of days saved in the time of voyages is also stated for vessels of 9, 10, 12, 14 and 16 knots speed, vessels of these speeds being selected because cargo carriers are usually operated at 9 to 12 knots, and passenger ships at 14 to 16 knots over most ocean routes, except those across the north Atlantic, where passenger steamers of 18 to 24 knots are largely employed.

A freight vessel operated at an average speed of 10 knots can make the run between New York and San Francisco by the Panama Canal in 32 days less time than is required for a voyage via the Straits of Magellan. Between New Orleans and San Francisco the time saved for a vessel of this speed would be 36 days. In these calculations, as in all others made in compiling these tables, a half day is added to allow for the time taken in passing through the canal. The "Kroonland" and "Finland", which are vessels of about 14 knots average speed at sea, are making the trip between New York and San Francisco in 16 or 17 days, including a half day at the canal and a call at San Diego or the Port of Los Angeles. If the "Kroonland" and "Finland" were to make the voyage via the Straits of Magellan, they would require 23 days additional time for the trip, and, if the daily expense of operating such a vessel is not more than $1000, the reduction in expenses effected by the use of the canal is $23,000 per trip, a sum much in excess of the $9,879.60 tolls paid by the "Kroonland" for the use of the canal. It should be stated, however, that such a comparison as this is not of great value, because it would not be profitable to operate the "Kroonland" and "Finland" between New York and San Francisco by way of the Straits of Magellan even in a combined freight and passenger service.

The distance and time saved by the use of the Panama Canal instead of the Straits of Magellan for voyages between Europe

TABLE I.—DISTANCES AND TIME SAVED VIA THE PANAMA CANAL AS COMPARED WITH THE STRAITS OF MAGELLAN BETWEEN THE ATLANTIC-GULF PORTS OF THE UNITED STATES AND THE WEST COAST OF NORTH AND SOUTH AMERICA.

To—	From New York.						From New Orleans.					
	Distance saved.	Days saved for vessels of—					Distance saved.	Days saved for vessels of—				
		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.		9 knots.	10 knots.	12 knots.	14 knots.	16 knot .
	Miles.						*Miles.*					
San Francisco	7,873	35.9	32.3	26.8	22.9	20.0	8,868	40.5	36.4	30.2	25.8	22.5
Callao	6,250	28.4	25.2	21.2	18.1	15.7	7,245	33.0	29.7	24.7	21.1	18.4
Iquique	5,139	23.3	20.9	17.3	14.8	12.9	6,134	27.9	25.0	20.8	17.7	15.4
Valparaiso	3,747	16.8	15.1	12.5	10.6	9.2	4,742	21.4	19.2	16.0	13.6	11.8
Coronel	3,296	14.7	13.2	10.9	9.3	8.1	4,291	19.4	17.4	14.4	12.3	10.7

TABLE II.—DISTANCES AND TIME SAVED VIA THE PANAMA CANAL AS COMPARED WITH THE STRAITS OF MAGELLAN BETWEEN EUROPEAN PORTS AND THE WEST COAST OF SOUTH AMERICA.

To—	From Liverpool.						From Antwerp.						From Gibraltar.					
	Distance saved.	Days saved for vessels of—					Distance saved.	Days saved for vessels of—					Distance saved.	Days saved for vessels of—				
		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.
	Miles.						*Miles.*						*Miles.*					
Callao	4,043	18.2	16.3	13.5	11.5	10.0	3,905	17.6	15.8	13.1	11.5	9.7	3,327	14.9	13.3	11.0	9.4	8.1
Iquique	2,932	13.1	11.7	9.7	8.2	7.1	2,794	12.4	11.1	9.2	7.8	6.8	2,216	9.7	8.7	7.2	6.1	5.2
Valparaiso	1,540	6.6	5.9	4.8	4.1	3.5	1,402	6.0	5.3	4.3	3.5	3.1	824	3.3	2.9	2.3	1.9	1.6
Coronel	1,089	4.5	4.0	3.3	2.7	2.3	951	3.9	3.4	2.8	2.3	1.9	373	1.2	1.0	0.8	0.6	0.5

and typical ports on the west coast of South America are stated in Table II, which gives the facts for voyages from Liverpool, Antwerp and Gibraltar to west coast South American points. A freight steamer of 10 knots speed can make the run from Liverpool to Callao in 16 days less time by way of Panama than via the Straits of Magellan. For trips from Liverpool to the nitrate port of Iquique, a 10-knot steamer can save 11.7 days. The saving in distance and time grows less for ports successively further south from the canal.

A freight steamer from Liverpool to Valparaiso will save 5 or 6 days via Panama, and a passenger steamer would save only 3½ or 4 days. If the saving in distance and time were the only factors affecting the choice of routes, it is not probable that much of the traffic between Valparaiso and Liverpool would be carried on by way of Panama; but the fuel cost, which is much less via Panama, and the opportunities for trade en route at west coast South American ports offer a strong reason for the selection of the Panama route, at least for the inbound or home voyage of vessels plying between Europe and Valparaiso. Since the opening of the canal, some vessels have been making the outbound voyage from Europe to Chile via the Straits of Magellan, and the return trip by way of the Panama Canal. It is probable that, as the commerce of the west coast of South America increases, the tendency to use the Panama Canal both for the outbound and return voyage will be stronger.

Before the opening of the Panama Canal the relatively large commerce between the eastern part of the United States and Australia and New Zealand was shipped via the Cape of Good Hope, the distance from New York to Australia via Suez being about the same as by way of the Cape of Good Hope. Table III shows the distance and time saved by using the Panama Canal instead of the route passing the Cape of Good Hope for voyages from New York and New Orleans to the Australian ports of Adelaide, Melbourne and Sydney. The table also shows the time and distances saved via Panama as contrasted with the route through the Straits of Magellan for voyages from New York and New Orleans to Wellington, New Zealand, the short route to New Zealand before the opening of the Panama Canal being by way of the Straits of Magellan.

TABLE III.—DISTANCES AND TIME SAVED VIA THE PANAMA CANAL AS CONTRASTED WITH ROUTES VIA THE CAPE OF GOOD HOPE, AND THE STRAITS OF MAGELLAN BETWEEN THE ATLANTIC-GULF SEABOARD OF THE UNITED STATES AND AUSTRALASIA.

To—	From New York.						From New Orleans.						Remarks.
	Distance saved.	Days saved for vessels of—					Distance saved.	Days saved for vessels of					
		9 knots.	10 knots.	12 knots.	14 knots.	16 nots.		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.	
	Miles.						*Miles.*						
Adelaide..	1,746	7.5	6.7	5.6	4.6	4.0	3,258	14.6	13.1	10.8	9.2	8.0	Difference between routes via Panama, Tahiti, Sydney and Melbourne, and via St. Vincent and Cape of Good Hope.
Melbourne	2,770	12.3	11.0	9.1	7.7	6.7	4,282	19.3	17.3	14.3	12.2	10.7	Difference between routes via Panama, Tahiti and Sydney, and via St. Vincent, Cape of Good Hope and Adelaide.
Sydney....	3,932	17.7	15.8	13.1	11.2	9.7	5,444	24.6	22.2	18.4	15.7	13.7	Difference between routes via Panama and Tahiti, and via St. Vincent, Cape of Good Hope, Adelaide and Melbourne.
Wellington	2,493	11.0	9.9	8.1	6.9	6.0	3,488	15.6	14.0	11.6	9.9	8.6	Difference between routes via Panama and Tahiti, and via Straits of Magellan.

TABLE IV.—DISTANCES FROM LIVERPOOL TO AUSTRALIA AND NEW ZEALAND VIA THE PANAMA CANAL AND VIA THE SUEZ CANAL, AND DISTANCES AND DAYS SAVED BY THE SHORTER ROUTE.

To—	Via—	Distance.	Distance saved via shorter route.	Days saved via shorter route for vessels of—					Remarks.
				9 knots.	10 knots.	12 knots.	14 knots.	16 knots.	
		Miles.	*Miles.*						
Adelaide.....	Panama..	13,478	....	....	....	....	....	....	Via Panama, Tahiti, Sydney and Melbourne.
	Suez.....	11,142	2,336	10.8	9.7	8.1	6.9	6.1	Via Aden, Colombo and King George Sound.
Melbourne..	Panama..	12,966	....	....	....	....	....	....	Via Panama, Tahiti and Sydney.
	Suez.....	11,654	1,312	6.1	5.4	4.6	3.9	3.4	Via Aden, Colombo, King George Sound and Adelaide.
Sydney......	Panama..	12,385	....	....	....	....	....	....	Via Panama and Tahiti.
	Suez.....	12,235	150	0.69	0.62	0.52	0.44	0.39	Via Aden, Colombo, King George Sound, Adelaide and Melbourne.
Wellington..	Suez.....	12,989	....	....	....	....	....	....	Via Aden, Colombo, King George Sound and Melbourne.
	Panama..	11,425	1,564	6.7	6.0	4.9	4.2	3.5	Via Panama and Tahiti.

The principal port of Australia is Sydney, and vessels making a voyage between north Atlantic ports and Australia, whether via the Suez Canal, the Cape of Good Hope, or the Panama Canal, will, in most instances, make the port of Sydney as well as the ports of Adelaide and Melbourne. Ten-knot freight steamers can save about 16 days by using the Panama Canal for trips from New York to Sydney. From New Orleans to Sydney, the saving in time for such vessels is 22 days. The trip to Wellington from New York can be made in about 10 days less time by way of the Panama Canal than through the Straits of Magellan. From New Orleans to Wellington, 14 days can be saved by the use of the Panama Canal. In general, the commerce between the Atlantic-Gulf seaboard of the United States, Australia and New Zealand is so assisted by the Panama Canal as to make uneconomical the use of other routes.

In order to show how the opening of the Panama Canal has altered the conditions of competition between the eastern part of the United States and Europe for the trade of Australia and New Zealand, Table IV is presented. It states the distances between Liverpool and Australia and New Zealand via the Panama and Suez canals, and shows that the Suez route is shorter than the Panama route for voyages between Europe and Australia; while for voyages between Liverpool and Wellington, New Zealand, the distance via Panama is somewhat less. The saving by the Panama Canal, however, is not enough to cause that route to be taken unless cheaper fuel expenses and larger traffic at intermediate ports may possibly make the Panama route the more profitable.

It will be seen by Table IV that Sydney, Australia, is almost equally distant from Liverpool via the Suez and Panama routes. A vessel sailing from Sydney, Australia, for Liverpool will, accordingly, select the Suez route if the master of the vessel needs to discharge and take on cargo at intermediate ports. If the vessel sails from Sydney with a full cargo for Liverpool, or some Channel or North Sea port, it will probably be more economical to take the Panama route, by way of which fuel costs will be less than via Suez. The use of the Panama Canal instead of the Straits of Magellan for voyages between Wellington and Liverpool will be determined mainly by two factors,—the

expense incurred for tolls at Panama, and the saving in fuel by way of the Panama route. Vessels will ordinarily not find it profitable to make the run of the entire distance from Wellington to Europe without coaling en route. The cost of coal along the route via the Straits of Magellan and the east coast of South America is so much higher than the cost of coal at stations along the Panama route as largely, if not fully, to offset the amount payable as tolls for passage through the Panama Canal.

The competition between the United States and Europe for the trade of the Orient has been increasingly active since 1900, and the opening of the Panama Canal has put the eastern part of the United States on a parity with Europe, as regards transportation conditions, for the Oriental trade. Table V states the distances and days saved for voyages from New York and from New Orleans via the Panama Canal, as compared with the Suez Canal, to the ports of Yokohama, Shanghai, Hongkong, Manila and Singapore. A 10-knot freight steamer can make the run from New York to Yokohama in 15 days less via Panama than via Suez. Between New Orleans and Yokohama, the saving for such voyages is 23 days. For a trip from New York to Shanghai, the Panama route is 7 days shorter than the Suez route for a 10-knot steamer, while from New Orleans the saving in time via Panama is 15 days.

It will be noted that Hongkong and Manila are almost equally distant from New York via the Suez and Panama routes, each route including the ports of call designated in the table. It is probable, however, that most of the commerce between the eastern part of the United States and the Philippines will be handled via Panama, because the trade with the Philippines will naturally be carried on by vessels engaged also in the trade with China and Japan, Manila being a terminal port for a voyage from New York to the East. Singapore is decidedly nearer New York via the Suez Canal than by way of Panama, and it is not probable that much traffic from Singapore to New York will be handled via Panama, although it may not infrequently happen that vessels outbound from Europe to Chinese and Japanese ports via Singapore may make a return trip to the United States or to Europe via the United States through the Panama Canal. Indeed, the commerce between the eastern part of the United

TABLE V.—DISTANCES AND DAYS SAVED BY THE PANAMA OR THE SUEZ CANAL BETWEEN THE ATLANTIC-GULF SEABOARD OF THE UNITED STATES AND JAPAN, CHINA, THE PHILIPPINES, AND SINGAPORE.

To—	Via—	From New York.						From New Orleans.						Remarks.
		Dis-tance saved.	Days saved for vessels of—					Dis-tance saved.	Days saved for vessels of—					
			9 knots.	10 knots.	12 knots.	14 knots.	16 knots.		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.	
		Miles.						*Miles.*						
Yokohama.	Panama..	3,768	16.9	15.2	12.6	10.7	9.3	5,705	25.9	23.3	19.3	16.5	14.4	Via San Francisco.
	Suez....	....	....	....	....	....	....	....	....	....	....	....	....	Via Colombo, Singapore, Hongkong and Shanghai.
Shanghai..	Panama..	1,876	8.1	7.3	6.0	5.1	4.4	3,813	17.1	15.4	12.7	10.8	9.4	Via San Francisco and Yokohama.
	Suez.....	....	....	....	....	....	....	....	....	....	....	....	....	Via Colombo, Singapore and Hongkong.
Hongkong.	Panama..	....	....	....	....	....	....	1,919	8.4	7.5	6.2	5.2	4.5	Via San Francisco, Yokohama and Shanghai.
	Suez.....	18	....	....	....	....	....	....	....	....	....	....	....	Via Colombo and Singapore.
Manila	Panama.	41	....	....	....	....	....	1,978	8.6	7.7	6.4	5.4	4.7	Via San Francisco and Yokohama.
	Suez.....	....	....	....	....	....	....	....	....	....	....	....	....	Via Colombo and Singapore.
Singapore.	Panama..	....	....	....	....	....	....	....	....	....	....	....	....	Via San Francisco and Yokahoma.
	Suez.....	2,484	11.0	9.8	8.4	6.9	5.9	547	2.0	1.7	1.4	1.1	.9	Via Colombo.

TABLE VI.—DISTANCES AND DAYS SAVED VIA THE SUEZ CANAL, AS COMPARED WITH THE PANAMA ROUTE, BETWEEN LIVERPOOL AND SINGAPORE, MANILA, HONGKONG, SHANGHAI, AND YOKOHAMA.

To—	Distance shorter via Suez than via Panama (nautical miles).	Days saved for vessels of—					Remarks.
		9 knots.	10 knots.	12 knots.	14 knots.	16 knots.	
Singapore	6,946	31.6	28.4	23.6	20.2	17 5	Panama route via San Francisco and Yokohama. Suez route via Colombo.
Manila	4,421	19.9	17.9	14.8	12.6	11.0	Panama route via San Francisco and Yokohama. Suez route via Colombo and Singapore.
Hongkong	4,172	18.8	16.8	13.9	11.9	10.3	Panama route via San Francisco and Yokohama. Suez route via Colombo and Singapore.
Shanghai......	2,776	12.3	11.0	9.1	7.8	6.8	Panama route via San Francisco and Yokohama Suez route via Colombo, Singapore and Hongkong.
Yokohama.....	694	2.7	2.4	1.9	1.5	1.3	Panama route via San Francisco. Suez route via Colombo, Singapore, Hongkong and Shanghai.

States and the Pacific ports of Asia from Shanghai to Singapore will be handled partly by way of Panama and partly via Suez, the route taken by vessels engaged in this trade being determined by fuel costs, necessary intermediate ports of call, and other well known factors that determine the movements of freight vessels.

As is shown in Table VI, the trade between Europe and China, the Philippines and Japan—with the possible exception of some of the Japanese trade—will be handled by way of Suez and not through the Panama Canal. A line connecting points equally distant from Liverpool via the Suez and Panama canals runs 347 miles east of Yokohama, making the distance from Yokohama to Liverpool 694 miles greater via Panama than via Suez. By the opening of the Panama Canal, the eastern part of the United States and the western part of Europe have been placed upon an equal footing, as regards distance, in competing for the trade of the Orient,—a fact that may be illustrated by drawing a line through the points equally distant from Liverpool via Suez and from New York via Panama. Such a line would pass close to Shanghai and through the center of Australia slightly to the west of Adelaide. Japan and northern China are nearer New York via Panama, while southern China and the Philippines are nearer Liverpool via Suez. Although the entire Orient is nearer Liverpool and other European ports vía Suez than via Panama, it may be economical for some of the traffic between Japan and Europe to be handled via Panama, because of lower fuel expenses, and because of the opportunity to engage in American commerce.

TONNAGE, CHARACTER AND SOURCES OF CANAL TRAFFIC.

The best test of the value of the Panama Canal will be the use made of it by the commerce of the world, and particularly by the shipping engaged in American commerce. In order to measure the services that would be rendered by a canal, if constructed, advance studies were made, at different times, of the tonnage of available traffic.

The Panama Canal Company, beginning in 1894, kept a card record for six years of the movements of practically all

vessels engaged in ocean freight transportation, and at the end of each year a calculation was made to ascertain the tonnage of canal traffic to which the vessels would have given rise had a Panama Canal been available. The records thus kept by the Panama Canal Company for six years were turned over to the Isthmian Canal Commission in 1900.

The writer of this paper, during the two years, 1899-1901, made an investigation of available canal tonnage. A study was made of the exports and imports of the United States and of Europe to ascertain the tonnage of cargo that would have been moved through the canal in 1899 or 1900, had there been a canal to use. A study was also made of vessel entrances and clearances at American and European ports to find out the tonnage of vessels whose movements were such that a Panama Canal would have been used. The results obtained by this investigation were substantially the same as the figures obtained by the Panama Canal Company, and the several studies showed that there were about 5,000,000 vessel tons of available Panama Canal traffic in 1899. In 1912, the writer made another investigation of available Panama Canal traffic, and found that the tonnage of vessels, whose movements were such that the use of the canal would have been advantageous, had increased by 1910 to 8,328,000 tons, or at the rate of 59 percent per decade.

The accuracy of this ascertained rate of increase of available Panama Canal traffic was checked by studies of the growth of the traffic of the Suez Canal, of the increase in the foreign trade of the United States with the world as a whole, of the trade of the United States with non-European countries, of the commerce between the Atlantic-Gulf seaboard of the United States and Pacific countries, and of the commerce between Europe and the west coast of North and South America. These investigations, as set forth in the report on ''Panama Canal Traffic and Tolls'', published in 1912, showed that the increase in available canal traffic had unquestionably been as much as 60 per cent per decade during the fifteen years ending with 1910. It was, accordingly, considered safe to assume that the traffic available for the Panama Canal in 1910 would increase at the rate of 60 percent per decade, and by 1915 reach about 10,250,000 vessel tons per annum.

The canal was opened for traffic August 15, 1914, before it was fully completed. Since it was opened for traffic, slides in the Gaillard (Culebra) Cut have, on a few occasions, interrupted the use of the canal for periods of one to five days, and these interruptions to traffic have doubtless somewhat delayed the establishment of regular services through the canal, and have possibly made the increase in the traffic of the waterway somewhat slower than the gain otherwise would have been.

The conflict in Europe started shortly before the canal was opened, and all advance estimates as to the use that would have been made of the canal have been thrown out of line by the war which has temporarily stopped the commerce of some nations and has seriously interfered with the international trade of most countries. It is probable that the European war has cut in half the tonnage of the Panama Canal traffic.

A very satisfactory record is being kept of the traffic of the Panama Canal, and figures of the cargo and vessel tonnage are published week by week in the ''Canal Record''. The use of the canal month by month, since August 15, 1914, is shown by the table on page 14, which gives the number of vessels that have passed eastbound and westbound through the canal, the number of tons of cargo that have moved in each direction, and also the gross and net tonnage of vessels that passed through the canal.

The table shows that the tonnage has increased substantially and has been appreciably larger since the first of March than it was before that time. During the first four full months, September to December, inclusive, the average cargo tonnage per month was 410,622 tons. During the four months March to June, inclusive, the average per month was 584,946 tons. For the month of June, 1915, the cargo tonnage amounted to 603,180 tons.

The commerce served by the canal is well shown by an analysis of the traffic with reference to five principal commercial routes. The table on page 15, compiled from the ''Canal Record'' of August 4, 1915, states the traffic for the month of June, eastbound and westbound, between the two seaboards of the United States, between Europe and the west coast of the United States and Canada, between Europe and western South and Central America, the United States and western South and Central America, and the United States and trans-Pacific countries.

Month	Eastbound		Westbound		Total		Vessel tonnage	
	Vessels	Cargo	Vessels	Cargo	Vessels	Cargo	Gross tons	Net tons
1914								
August	11	62,178	13	49,106	24	111,284	120,282	85,978
September	30	180,276	27	141,762	57	322,038	303,446	221,059
October	40	253,288	44	168,069	84	421,357	461,104	328,216
November	38	242,291	54	206,510	92	448,801	452,550	322,731
December	57	271,219	43	179,235	100	450,454	485,672	344,294
1915								
January	54	240,925	44	208,082	98	449,008	490,571	347,212
February	53	276,078	39	150,987	92	427,065	455,344	322,862
March	80	417,610	57	217,447	137	635,057	675,281	475,984
April	60	285,457	59	237,384	119	522,841	569,877	404,539
May	75	332,174	67	246,534	142	578,708	703,805	492,350
June	60	282,561	83	320,619	143	603,180	698,855	497,810
Total	558	2,844,057	530	2,125,735	1088	4,969,792	5,416,787	3,843,035

Route	Tons of cargo	
Coastwise, eastbound	105,946	
Coastwise, westbound	91,181	
Total		197,127
West coast of United States and Canada to Europe	31,031	
Europe to west coast of United States and Canada	15,914	
Total		46,945
South and Central America to Europe	58,001	
Europe to South and Central America	12,984	
Total		70,985
South and Central America to United States	80,558	
United States to South and Central America	68,934	
Total		149,492
Far East, including Australia, to United States	7,025	
United States to Far East, including Australia	120,356	
Total		127,381
Miscellaneous, eastbound	....	
Miscellaneous, westbound	11,250	
Total		11,250
Grand total		603,180

During June, 1915, 32.6 percent of the cargo tonnage passing through the canal consisted of traffic between the two seaboards of the United States. The coastwise commerce, the traffic between the United States and western South and Central America, and the trade between the eastern United States and trans-Pacific countries made up 78.5 percent of the total traffic of the Panama Canal for the month of June, 1915. A comparison of the facts contained in this table with the figures of available Panama Canal traffic contained in the report upon "Panama Canal Traffic and Tolls" will show some of the effects of the war upon the world's commerce and upon the use of the canal by that commerce. Of the tonnage of shipping that would have used a Panama Canal had the waterway been in existence in 1910, 37.8 percent would have consisted of shipping engaged in commerce between Europe and western South America; the commerce of Europe through the canal would have comprised 62½ percent of

the total canal tonnage; while the commerce between the eastern United States and western South America would have comprised 5.6 per cent. It was estimated that the traffic between the two seaboards of the United States during the first year or two of the canal would not amount to more than 10 or 11 percent of the total canal tonnage, and that the vessels employed in the trade of the United States with foreign countries would constitute about 33 percent of the total Panama tonnage. These estimates indicate that about 56 percent of the shipping using the canal would be employed in commerce that did not touch the shores of the United States.

These comparisons show that the ratio of the intercoastal traffic to the entire tonnage of the Panama Canal is 3 times the ratio that was predicted, and that the intercoastal and foreign commerce of the United States making use of the canal accounts for 78.5 per cent of the canal tonnage instead of for 44 percent as was estimated. The canal tonnage as a whole is about one half what was expected. This difference between prediction and experience is believed to be accounted for by the European War.

The effect of the war upon the traffic of the canal may be illustrated by reference to the shipments of nitrate from Chile. Nitrate exports normally amount to 2,500,000 cargo tons annually. Before the opening of the canal, roughly four fifths of the nitrate went to Europe, mainly to Germany, Belgium and other sugar producing countries, and one fifth to the United States. During the month of June, 1915, the nitrate shipments to Europe amounted to only 41,251 tons, while the shipments to the United States, instead of being one fifth of the shipments to Europe, were 40 percent more than the European tonnage, the amount being 58,824 tons. During the three months of April, May and June, 1915, the total shipments to Europe amounted to 135,404 tons, and to the United States, 168,092 tons. These figures show that the nitrate shipments as a whole are only a fraction of the normal amount, and that the war has stopped nearly all of the purchases of nitrate by European countries.

As was expected, the traffic through the canal, both eastbound and westbound, comprises a large number of commodities. This is especially true of the trade between the two seaboards of

the United States. It will be noted from the above table that during the month of June, 1915, the westbound intercoastal shipments amounted to 53.3 percent of the coast-to-coast traffic through the canal, the westbound shipments consisting mainly of coal, coke and manufactures. Among the manufactures shipped from the eastern seaboard to the west coast of the United States in large quantities were iron and manufactures of iron and steel, petroleum and textiles. ''General cargo'', including a wide range of manufactures, makes up a large share of the westbound intercostal traffic through the canal. The eastbound shipments through the canal also include many kinds of commodities, although the number of articles shipped eastbound is less than the number of those moving in the opposite direction. Sugar from the Hawaiian Islands to New York is a large single item of eastbound traffic. The heavy movement of nitrates to the United States has already been mentioned. The opening of the canal made possible the establishment of a fleet of ore carriers to bring iron ore from Chile to Philadelphia, and between 15,000 and 20,000 tons of that ore are being brought to Philadelphia each month. When business revives, it is probable that this iron ore tonnage will be much larger. Lumber in relatively large tonnage is shipped through the canal to the east coast of the United States, to Canada and across the Atlantic to England. Flour from the west coast is shipped mainly to Europe.

The commerce between the eastern seaboard of the United States and trans-Pacific countries via the canal is worthy of especial notice. The lines that have formerly been operated between New York and Australia by way of the Cape of Good Hope have been changed to the Panama route. Likewise the commerce between the eastern seaboard of the United States and the Pacific coast of Asia is being handled through the canal. During the three months of April, May and June, 1915, the total cargo tonnage between the eastern seaboard of the United States and trans-Pacific countries was 300,530. The establishment of direct steamship services between the eastern seaboard of the United States and trans-Pacific countries has already tended to lessen the importance of Europe as a market for the Australian and Oriental goods imported into the United States. London has been, and probably will continue to be, the

great wool market of the world, but shipments of wool have already been made via the canal from Brisbane to New York and from Melbourne to Boston. These direct shipments doubtless indicate that a larger share of the Australian wool brought into the United States will, in the future, come directly via the canal and a smaller share indirectly via the London market. What is true of wool will be true of other commodities received from trans-Pacific countries, and the canal may be expected gradually to increase direct trading between the United States and Pacific countries with which commerce up to the present has been carried on largely by way of Europe. The shifting of markets due to the establishment of new transportation routes is a slow process, and the influence of the canal upon the relocation of the world's primary trade centers will be gradual, but, in the long run, of great importance to the United States.

The use made of the Panama Canal by American manufacturers and traders will depend upon the extent to which the steamship lines operating through the canal are able to compete with the rail lines connecting the eastern and western parts of the United States for traffic originating or terminating at interior points. It is too early to reason with any degree of finality concerning the ability of the coastwise carriers to secure traffic between the Mississippi Valley and the Rocky Mountain States. There is no doubt, however, that the rail and water lines will actively compete for large west-coast shipments to and from all points between the Atlantic seaboard and places as far west as St. Paul and St. Louis. For the most part, the traffic of the eastern part of the United States will move to the west-coast states by rail, but there will be active and continuous competition for a portion of this traffic.

In the report which the Interstate Commerce Commission submitted January 29, 1915, concerning the application of the long and short haul section of the interstate commerce act to rates to Pacific coast terminals and intermediate points, the Commission states that the testimony shows

". . . . a reaching out by these water carriers to territory from which heretofore they have drawn but little if any traffic, and the movement by water of various commodities that heretofore have moved almost exclusively by rail. Prominent

instances of these are the following: A shipment of 32 cars of cast-iron pipe from Birmingham, Ala., by rail to New Orleans, thence by water to the Pacific coast; a shipment of paper bags from Sandy Hill, N. Y., via New York and ocean; shipments of catsup from Rochester, N. Y., via New York and ocean; 140 cars of structural iron originating in various parts of Pennsylvania; 50 cars of wire fencing from various points in Pennsylvania; 1200 tons of rails from Lorain, Ohio; 653 pieces of wrought-iron pipe from Wheeling, W. Va.; from 10,000 to 15,000 tons of wrought-iron pipe from Youngstown, Ohio''.

Flour from St. Paul to the Orient has recently been shipped via New York and the canal and from time to time shipments are made to the west coast of the United States and to trans-Pacific countries via the Atlantic seaboard and the canal from points between the Alleghany Mountains and the Mississippi River. The competition of the coastwise carriers for traffic from and to the section west of the Alleghanies is mainly for large individual shipments. Only a part of any one producer's output will ordinarily be sent via the canal instead of by rail; but the canal route, by drawing commodities of many kinds from many points west of the Alleghany Mountains, will steadily increase the tonnage of canal traffic, gradually build up production and widen the markets of American made goods; and, incidentally, bring about two other results that require consideration, a shifting of some industries or of some manufacturing activities from the interior to or near the seaboard and a readjustment of the rates charged by the transcontinental rail lines.

PROBABLE INFLUENCE OF THE CANAL UPON THE LOCATION AND DEVELOPMENT OF AMERICAN INDUSTRIES.

There has been apprehension on the part of manufacturers in the central section of the United States and also on the part of the railroad companies whose lines connect the Mississippi Valley with the Pacific coast lest the Panama Canal may cause the rates coastwise between the two seaboards to be so much lower than the rates all-rail or by rail-and-ocean between the section extending from the Alleghany Mountains to the Missouri River and the section along and tributary to the west coast as

to make it impossible for some producers at interior points to compete successfully with producers at or near the seaboard, and in consequence to bring about the shifting of some industries from the Mississippi Valley to the Atlantic seaboard states and to cause new industries to be located near the seaboard rather than in the inland cities.

Producers located at inland points will, without doubt, have to pay higher rates on goods shipped in either direction between the eastern and western sections of the United States, and producers located at or near the Atlantic and Gulf seaboards will enjoy lower rates than can be secured by producers at interior points, not only on traffic between the two seaboards of the United States, but on shipments to and from western South America, Australasia and the Orient. On account of these changes in rates at and near the seaboard, manufacturers having plants both at inland cities and at places on or near the seaboard will, probably, when it is practicable to do so, turn over to their seaboard plants orders for foreign shipment and orders requiring the shipping of goods between the two seaboards of the United States. This division of the work between inland and seaboard plants would naturally be made in the production of plates, rails, nails, and other heavy manufactures, the freight rates upon which will amount to a considerable percentage of the selling value.

The advantage in freight rates which seaboard plants will have because of the canal may also be expected to result in the erection of some plants at or near the seaboard that would, if there were no canal, be constructed at inland points. The influence of the canal on the location of industries may, however, be easily exaggerated. The United States as a whole is so large, its industries are so varied and so widely distributed through the country, and the interstate commerce by rail is so many times greater than the entire traffic through the canal will ever be that the commerce by way of the canal between the two seaboards of the United States and between either of those seaboards and foreign countries can be only one of the many forces that will influence the location of industries. The greatest factor determining the location of industries in the United States is the domestic market. A second, and a most influential, factor, is

the source of raw materials. While freight rates are a third influence that determines where plants shall be constructed and industries be conducted, freight rates are not the strongest influence determining the distribution of industries. It often happens that the ability to ship by rail to all points of the country with dispatch and with a minimum handling of goods will cause an industry to locate at an inland point, although by locating at or near a seaport lower freight rates could be obtained.

The first and most direct effect of the Panama Canal is its influence upon ocean freight rates, but inasmuch as transportation rates are but one of the items in the cost of production, the indirect and most important benefit of the canal is the aid it renders in the development of industries. It will hardly be necessary in this paper to set forth in detail the relation of the Panama Canal to the industrial development of different sections of the United States. In a report upon "The Industrial and Commercial Value of an Isthmian Canal", published in 1901 as a part of the Report of the Isthmian Canal Commission, and reprinted in 1912 as an appendix to the report upon "Panama Canal Traffic and Tolls", the writer has considered at length the relation of the canal to the industries and trade of the eastern, southern, central and western sections of the country. This report also contains separate chapters upon the relation of the canal to the coal trade, the iron and steel industries, and the shipbuilding and maritime interests of the United States.

The general industrial effect produced by the Panama Canal through its reduction of the expense of transportation is to afford a wider market within and without the country for the products of the mills and factories of American producers. The distance at which many kinds of goods can be marketed depends directly upon transportation costs. Moreover, success in many markets depends upon conditions of competition. For the trade of the United States with western South America, Australia and the Orient, the canal has made it possible for American industries to compete much more readily with European industries, and, as time passes, the favorable effect of these improved conditions of competition should become increasingly evident.

The analysis given above of the traffic of the canal shows that the iron and steel and other manufacturing industries in

the eastern and central parts of the United States have already begun to make much use of the canal to reach markets in the western part of the United States and in trans-Pacific countries. Cargoes of southern cotton, lumber, coal and heavy iron products have been sent through the canal to Pacific markets, and there can hardly be any doubt that year by year, and decade by decade, the Panama Canal will assist in building up the industries and trade of the eastern and southern sections of the country.

It was the states on the Pacific coast that had the greatest interest in the construction of the canal. Manufacturing being in an early stage of development, those states were, before the opening of the canal, obliged to secure manufactured goods mostly by rail, and to pay high freight rates for the long and expensive haul from the eastern and central sections of the country over the Rocky Mountains barrier. Likewise, the people of the west coast section had to pay high freight rates on their grain, lumber, fruit, fish and other staple products. The Panama Canal has enabled the west coast of the United States to reach the markets of both sides of the Atlantic readily and inexpensively, and has prepared the way for the expansion of west-coast industries at an even more rapid rate than has thus far characterized their development.

THE CANAL AND RAILWAY RATES AND TRAFFIC.

The first railroad connecting the Mississippi Valley and the Pacific coast, the Union Pacific-Central Pacific line, was opened in 1869. During the next fifteen years several other railroads to the Pacific were constructed. Before the first railroad was built through to the Pacific, traffic was handled between the two seaboards of the United States by way of the Isthmus of Panama, across which a railroad connecting Colon and Panama was opened in 1855. Before the Panama route was available, traffic was carried between the two seaboards by sailing vessels around Cape Horn and by steamers through the Straits of Magellan, and, in 1907, seven years before the opening of the Panama Canal, commerce between the two seaboards of the United States had begun to be handled in relatively large volume by way of the Isthmus of Tehuantepec.

These various routes coastwise between the two seaboards, though the service via the Isthmus was more or less under the influence of the transcontinental railroad companies, regulated through railroad rates between the eastern and western sections of the country. A reference to the main features of the present transcontinental railway rate structure will show how the competition of the coastwise carriers has influenced the freight charges of the Pacific railroads:

(a) The through rates between the two seaboards are lower than the charges for the shorter haul to and from intermediate points in the Rocky Mountain States. The rates from New York or Pittsburgh to points in Nevada or Utah are higher than the rates to California; likewise rates from Nevada, Utah or Idaho to the eastern part of the United States are usually in excess of charges from points at or near the seaboard in California, Oregon and Washington.

(b) The westbound rates to the intermediate points, until recently, have usually been the sum of the through rate plus the local rate from the nearest Pacific coast terminal to the intermediate point of destination, i. e., the rate from Philadelphia to Reno, Nevada, has formerly been the rate to Sacramento, the nearest Pacific coast "terminal", plus the local rate from that terminal to Reno. Some intermediate rates, particularly the rates to intermountain points on the northern transcontinental lines, have been the sum of the rates to or from the Pacific coast terminal plus a differential somewhat less than the local rate between the seaboard terminal and the intermediate point.

After a long contest carried on by the shippers in the intermountain territory against these higher rates at intermediate points, the Interstate Commerce Commission, in 1911,* established a percentage adjustment between the through and intermediate rates on westbound shipments. The decisions of the Interstate Commerce Commission in the Reno and Spokane cases, which were later upheld by the Supreme Court,† provided that, on traffic originating at the Missouri River and points

* Railroad Commission of Nevada vs. Southern Pacific Co. et al., I. C. C. Reps., XXI, 329-84; City of Spokane et al., vs. Northern Pacific Co., et al., *Ibid.*, XXI, 400-27.

† Intermountain Rate Cases, 234 U. S. 476. Decided June 22, 1914.

west thereof (Zone 1), the rates to intermediate points should not be higher than the rates through to the Pacific coast terminals; that on traffic originating in the Chicago territory and at points between Chicago and the Missouri River (Zone 2), the rates to intermountain points should not exceed by more than 7 percent the through rates to the coast; that, on shipments originating in the Buffalo-Pittsburgh territory and in the section between that territory and Chicago (Zone 3), the rates to intermountain points should not exceed the through rates by more than 15 per cent; and that, on traffic from the section between the Buffalo-Pittsburgh district and the Atlantic seaboard (Zone 4), the rates to intermountain points should not exceed the rates through to the Pacific seaboard terminals by more than 25 per cent. These percentages indicate the Commission's estimate of the influence of the Panama and Tehuantepec routes upon the transcontinental railroad rates before the opening of the Panama Canal.

(c) Another effect of the competition of the coastwise lines with the transcontinental railroads was the blanketing of westbound railroad rates over the eastern half of the United States. The rates to the west coast on most commodities were the same from all points east of the Missouri River, i. e., the same rate prevailed from New York, Chicago, St. Louis and Kansas City to west-coast points. This system of blanketing rates has prevailed since 1896. Both class rates and commodity rates westbound as well as eastbound are stated by so-called "rate groups" or zones into which the eastern half of the United States is divided. In the case of class rates, there is some grading of charges by rate groups on westbound traffic, and to a greater extent upon eastbound freight. However, most commodities shipped from the eastern half of the United States to the west coast pay the same rate whether shipped from the Atlantic seaboard section or from the central west.*

As stated in the report upon "Panama Canal Traffic and Tolls":

"The through route between the two seaboards via the Southern Pacific Railroad from the Pacific coast to Galveston and

* For a full explanation of transcontinental freight rates, see chap. xxiv, vol. I, "Railroad Traffic and Rates" by Johnson and Huebner, 1911.

New Orleans and from those cities to New York by the Southern Pacific Company's steamers (the Morgan Line) was established in 1883. The Sunset-Gulf route immediately began an active warfare against its competitors by rail and by water lines, and secured a large share of the traffic from coast to coast. The transcontinental railroads, other than the Southern Pacific, ran from the Mississippi and Missouri rivers to the Pacific coast and were primarily interested in the development of traffic between the middle west and the Pacific coast. The rates by the Sunset-Gulf route from New York to San Francisco were made the same as the rates by the transcontinental lines from St. Louis and Missouri River crossings to the Pacific. Gradually the rates by the through all-rail lines from the Atlantic to the Pacific were made the same as the rates from Chicago, St. Louis and Missouri River crossings to the Pacific seaboard. This system of blanket rates was worked out by 1896, and has since prevailed on westbound traffic."

This policy of the Southern Pacific had much to do in bringing about the blanketing of westbound transcontinental rates. The other cause that brought about this system of blanketing rates was the insistence of manufacturers in Chicago, St. Louis, St. Paul and other central western points, as well as the demand of the railroads connecting the Mississippi Valley with the Pacific coast, that the middle west should be allowed to market its products on the west coast in even competition with manufacturers located at or near the Atlantic seaboard whose rates by rail to the Pacific coast were regulated by competition between the coastwise and rail lines.

Eastbound rates from west-coast points to places on and east of the Missouri River were, in part, blanketed over the territory east of the Missouri River, but the system of blanketing the territory east of the Missouri River did not prevail so fully in eastbound as in westbound tariffs. Eastbound rates were, and still are, graded by zones, or by so-called "rate groups", as explained above, but in the case of fruit, lumber and other important commodities there is little grading of rates as between different parts of the territory east of the Missouri River.

Such was the system of transcontinental railroad rates at the time of the opening of the canal. Shortly before the canal

route became available, the Supreme Court had, as stated above, upheld the decisions of the Interstate Commerce Commission in the Intermountain Rate cases and the Commission had issued an order establishing the percentage adjustment above described between the through rates to the west coast and the rates to intermediate intermountain points. Had that system of percentage adjustments remained unchanged, the effect of the canal upon through rates by rail between the two seaboards would have been to have determined automatically the rates to intermediate intermountain points. The Pacific railroads, supported by certain business interests in the middle west, were, however, desirous of securing authority to reduce rates by rail from the middle west to the Pacific coast without being obliged thereby to lower the charges to intermediate places in the Rocky Mountain territory; and the Interstate Commerce Commission was petitioned to permit the reduction of some through rates without making a change in the intermediate charges. In other words, the Interstate Commerce Commission was petitioned to modify its decisions in the Spokane and Reno cases; and, after hearings held in October, 1914, the Interstate Commerce Commission, in an opinion rendered January 29, 1915, permitted the railroads under certain limitations to reduce the through rates to the west coast without lowering the charges to intermediate points in the Rocky Mountain territory on a list of articles including the commodities for the transportation of which the competition between the rail and water lines is most active.*

In this opinion the Commission considers fully the effect of the rates by the canal upon the traffic and charges of the transcontinental railroads. In presenting their case to the Commission, the carriers divided the commodities carried by the transcontinental railroads into three schedules, A, B and C. In schedules A and B were placed articles upon which the rates had been published by the carriers in accordance with the prior order of the Commission fixing the percentage adjustment between the rates to the seaboard and to intermediate points. In schedule C were listed the articles upon which the carriers wished to establish through rates lower than the rates to intermediate points by

* Commodity Rates to Pacific Coast Terminals and Intermediate Points, I. C. C. Reps. XXXII, 611-58; *Ibid.* XXXIII, 13-20.

an amount greater than permissible under the Commission's percentage adjustment.

After comparing the rates by rail on the leading articles in schedule C with the rates being quoted in September, 1914, by coastwise carriers, and after pointing out the fact that the traffic moving by canal was of large volume comprising many kinds of commodities drawn from the middle west as well as from the Atlantic seaboard section of the country, the Commission reached the opinion that

"Whatever may have been the degree of competition in the past between the rail carriers and the water carriers as to the rates on these articles concerning which additional relief is now sought, we are witnessing the beginning of a new era in transportation between the Atlantic and Pacific coasts. To secure any considerable percentage of this coast-to-coast traffic, rates on many commodities must be established by the rail lines materially lower than those now existing."

The Commission took the position that the railroads should be permitted to compete with the coastwise lines for traffic as long as the rates secured by the railroads "clearly cover the out-of-pocket cost." In justification of this position, the Commission makes the following statement of its view as to the policy that should be followed in adjusting the competitive relations between the railroads and the Panama Canal:

"It has been suggested that the construction of the Panama Canal by the Government of the United States is indicative of a governmental policy to secure all of this coast-to-coast business for the water lines, and that no adjustment of rates by the rail lines should be permitted which will take away traffic from the ocean carriers which normally might be carried by them. This suggestion, however, loses force under the consideration that the Panama Canal is but one of the agencies of transportation that the Government of the United States has fostered between the Atlantic coast and the Pacific. The Government has from the beginning of railroad construction in the United States encouraged their construction and operation by private capital and enterprise. Some of these transcontinental lines would not have been built had it not been for the liberality the Government extended to them at the time of their construction. As we view

it, the Panama Canal is to be one of the agencies of transportation between the east and the west, but not necessarily the sole carrier of the coast-to-coast business. If the railroads are able to make such rates from the Atlantic seaboard to the Pacific coast as will hold to their lines some portion of this traffic with profit to themselves, they should be permitted so to do. The acceptance of this traffic will add something to their net revenues, and to that extent decrease, and not increase, the burden that must be borne by other traffic. It will also give the shippers at the coast points the benefits of an additional and a competitive service''.

In adjusting the transcontinental railroad rates to carry out this view, the Interstate Commerce Commission authorized some important modifications of the percentage relationship that was established, and still exists, between the through rates to the west coast and the rates to intermediate points from the four zones into which the United States, other than the section south of the Ohio and Potomac (Zone 5 which is not included in the percentage rate adjustment), has been divided.* The present rate adjustment indicates concretely the effect which the Panama Canal has actually had upon the rates of the transcontinental railroads.

For the commodities included in the railroad companies' schedules A and B, the percentage adjustment as between through and intermediate rates is continued without modification; but for the commodities included in schedule C, a greater difference between the through and intermediate rates than was provided for by the percentage adjustment is permitted in the case of certain designated commodities and under specified limitations. The adjustment of rates, effective May 1, 1915, for schedule C commodities was, in general, as follows:

From points on the Missouri River and in the territory west thereof (Zone 1), carload rates to intermediate points are not to exceed those to Pacific coast terminals, except for a list of 28 articles or commodity groups which consist, for the most part, of various kinds of iron and steel manufactures. In the case of this excepted list the through rates, as filed by the carriers, may

* The order of the Interstate Commerce Commission, in its decision of January 29, 1915 (I. C. C. Reps., XXXII, 659), defines the boundaries of the five rate zones.

be less than the intermediate rates, provided that the rates to intermediate points in no instance exceed 75 cents per 100 pounds.

Carload rates through to the Pacific seaboard from Zones 2, 3 and 4 may be higher than the intermediate rates for articles listed in schedule C (with the exception of six exempted commodities and of 27 items that were withdrawn by the carriers from their petition), provided the rates to intermediate intermountain points from points in Zones 2, 3 and 4 do not exceed the rates from the Missouri River to the same destinations by more than 15, 25 and 35 cents per 100 pounds respectively. In the case of coal and pig iron, the rates to the Pacific coast may be lower than the rates to intermediate points, provided the intermediate rates do not exceed 5 mills per ton per mile.

For commodities in schedule C the through rates on less than carload shipments from points in Zone 1 may be lower than the rates to intermediate points on "all articles listed as first or second class in western classification upon which the rates to the terminals are less than \$1.50 per 100 pounds, and on all articles listed as third or lower class on which the rates to the terminals are less than \$1.25 per 100 pounds, provided that on and after May 1, 1915, the rates to intermediate points on all such first and second class articles do not exceed \$1.50 per 100 pounds, and on all such third or lower class articles \$1.25 per 100 pounds."

Less than carload commodity rates from points in Zones 2, 3 and 4 to Pacific coast terminals, as filed by the carriers, may be lower than the rates to intermediate points, provided "the rates to intermediate points do not exceed the rates from the Missouri River to the same destinations by more than 25, 40 and 55 cents per 100 pounds from points in Zones 2, 3 and 4, respectively".

With the permission of the Interstate Commerce Commission the through rates from the eastern half of the United States to the Pacific seaboard are made enough lower than the rates to intermediate points to enable the railroads to engage actively in competition with the coastwise lines operated via the Panama Canal. For territory within 200 miles of the Pacific coast, the rates directly by rail from the east are fixed by adding to the low through rate to the Pacific coast terminal 75 percent of the

local rate from the nearest terminal to the point of destination in the "back haul" territory within 200 miles of the Pacific coast, provided the sum of the through rate and 75 percent of the local "back haul" rate is not greater than the maximum prescribed for intermediate points in the adjustment above described. The Pacific coast ports included by the Interstate Commerce Commission in the list of cities to which terminal rates are allowed are San Diego, San Pedro, East San Pedro, Wilmington, East Wilmington, San Francisco, and Oakland, Cal.; Astoria and Portland, Ore., Vancouver, Bellingham, South Bellingham, Everett, Tacoma, Seattle, Aberdeen, Hoquiam, and Cosmopolis, Wash.

This complicated adjustment of the rates of the railroads connecting the Mississippi Valley with the Pacific coast will, doubtless, have the effect of enabling the Pacific railroads to compete successfully with the routes by rail to the seaboard and on by intercoastal water lines for the traffic between the middle west and the Pacific coast. The rate adjustment will also assist the middle west in competing with the industries at or near the Atlantic seaboard for the west coast business. Shippers in the intermountain section of the United States are very naturally opposed to a system of rates that makes charges to the intermediate points in the Rocky Mountain States higher than the through rates to the Pacific coast, and the permanence of the present rate adjustment will depend upon whether the people in the intermountain states will, in the future, be able to make their opposition effective.

The probable effect of the Panama Canal upon the rates and traffic of the Pacific railroads was discussed as follows by the writer, in 1901, in the "Report on The Industrial and Commercial Value of the Isthmian Canal."

"The competition of the canal will affect, first, the volume and rates of the through business of the Pacific railroads, and secondly, the amount of their local traffic. At the beginning of their existence these railways depended almost entirely upon their through traffic; but their chief aim throughout their history has been to increase the local business, which is always more profitable than the through traffic; and although the great stretch of country crossed by them is still in the infancy of its industrial

development, the local traffic of some, if not all, of the Pacific roads has already become of chief importance. A vice-president of one of the railway systems states that since 1893 'the increase in business of the transcontinental lines has not come from the seaports, but from the development of the intermediate country.' The canal can certainly in no wise check the growth of this local traffic, and the evidence strongly supports the belief entertained by many persons that the canal will assist largely in the industrial expansion of the territory served by the Pacific railways.

"If this be true, the proximate effect of the isthmian canal in compelling a reduction and readjustment of the rates, on the share of the transcontinental railway business that will be subject to the competition of the new water route, will be more than offset by the ultimate and not distant expansion of the through and local traffic, that must necessarily be handled by rail. It seems probable that the increase in the population of the country, and the growth in our home and foreign trade, will early demonstrate the need of the transportation service of both the canal and the railways".

THE CANAL AND AMERICAN SHIPPING AND COMMERCE.

From the analysis of the traffic that has used the canal since it was opened it is evident that the canal will be largely used by the commerce between the two seaboards of the United States. Five regular steamship lines, including 47 vessels, are operated between the two seaboards. The largest of these lines is that of the American-Hawaiian Steamship Company which owns 26 vessels, most of which are continuously in the intercoastal service through the canal. This company has sailings each way every five days. During the 7½ months from August 15, 1914, to April 1, 1915, the vessels of the American-Hawaiian Steamship Company made 94 transits through the canal carrying an aggregate of 699,342 tons of cargo, an average of 7440 tons per vessel. The Luckenbach Steamship Company maintains sailings each way about every 10 days, while the other lines have sailings once in three weeks or once in a month. By means of these several lines there are services through the canal from Boston, Phila-

delphia, Baltimore, Charleston and New Orleans on the Atlantic-Gulf coasts to San Pedro, San Francisco, Portland and Puget Sound on the Pacific coast.

The services of the intercoastal steamship lines are supplemented by those of chartered vessels and of vessels owned by individual shippers of lumber. There is every indication that the coastwise business through the canal will increase steadily and will constitute an important part of the traffic of the canal as a whole.

The effect of the canal upon the shipbuilding industry has been noticeable for two years. For a year before the opening of the canal vessels were being constructed with reference to the canal service, and the large tonnage which the intercoastal lines have been able to secure has led to the construction of additional ships for the coast-to-coast service via the canal. Vessels built abroad have been purchased by American firms for foreign trade through the canal.

As has been pointed out in this paper, the use of the Panama Canal for the traffic between the eastern seaboard of the United States and western South America and trans-Pacific countries has been relatively large, in spite of the limitations which the war in Europe has placed upon the purchasing power of South America and other countries. The Panama Canal will, without doubt, assist the United States in building up a trade with western South America, Australasia and the Orient. It is not to be expected, however, that this increase in commerce will be rapid. The canal will not suddenly revolutionize American trade relations. Most of the commerce of Pacific countries, Asiatic and American, is with Europe and not with the United States. For decades European countries have been investing capital in foreign countries and have been systematically developing international banking facilities. The manufacturers and exporters of Europe have built up a foreign trade and have established branch houses as outposts in South America, Australia and the Orient.

In order to divert from Europe to the United States a large share of the trade of western South America, Australia and the Orient now carried on with Europe, it will be necessary for American financiers to interest themselves in foreign investments, for American bankers to establish branches in foreign

countries, and for American merchants to adopt the merchandising methods which their European competitors have successfully followed in securing South American, Australian and Oriental trade.

The Panama Canal will assist in the development of the commerce of the United States with Pacific countries, but the shifting of commercial connections will be gradual. The traders of Europe with the assistance of the Suez Canal and by employing skilful merchandising methods, have secured the major share of the trade of the Orient and of Australasia. Europe now has the advantage of a prior occupation of the field, and of a thorough knowledge of the methods required to secure commerce. American manufacturers and traders can make great use of the Panama Canal in connection with other agencies for building up the foreign commerce of the United States, but the other agencies must be employed in order to enable the canal to be of large service.

POLICY TO BE FOLLOWED IN MANAGING THE CANAL.*

The Government of the United States has successfully carried through the difficult task of constructing the Panama Canal, and the great waterway has been opened to the commerce of all nations under terms of equality. What should be the policy of the United States in the management of the canal? In the long run, the management of the canal will probably test the ability of the Government as fully as did the construction of the waterway. The eyes of the entire world were upon the United States during the period of construction, and the President, having been given by Congress unrestricted power to build the canal, was able to construct the waterway with efficiency and with great credit to our country. Business methods prevailed and succeeded. In the management of the canal, there should be the same strict adherence to business principles.

Tolls have been fixed to be paid by all vessels using the Panama Canal. The tonnage of the waterway will, it is believed, within ten years, be sufficient to enable the Government to make

* Cf. address upon "The Panama Canal and Its Problems", published in "Old Penn", of the University of Pennsylvania, Vol. XIII, No. 27, April 3, 1915.

the canal commercially self-supporting, providing the present rate of tolls is maintained and is exacted of all vessels, American as well as foreign. Doubtless, pressure will be brought from time to time upon Congress and the President to lower the rate of tolls. The Government should resist this pressure until the revenues derived from the canal cover the annual operation and maintenance expenses and the interest on what it cost to build the waterway.

The schedule of tolls fixed by proclamation of the President, issued November 14, 1912, makes the charge for the use of the canal $1.20 per net vessel ton, there being a 40 percent reduction from the charges in the case of vessels passing through the canal without passengers or cargo. The tolls upon warships were placed at 50 cents per ton of weight or displacement. The tolls upon merchant ships were placed upon the net tonnage of the vessels, because it was deemed wise to base the charge upon the earning capacity of vessels. The ton as applied to the vessel does not mean weight, but 100 cubic feet of space. The space or tonnage upon which tolls are paid includes that part of the vessel that is available for the stowage of freight or for the accommodation of passengers. The rate of $1.20 per vessel ton was adopted, because it was found after investigation that a charge of that amount would not prevent the use of the canal by any considerable volume of traffic. This rate is also practically the same as that charged by the Suez Canal Company for the use of its waterway.

The revenues derived from the canal will depend upon the rate of tolls and upon the rules applied in the measurement of vessels to determine the number of tons upon which the tolls shall be paid. The revenues needed to make the canal commercially self-supporting will amount to about $20,250,000 per annum. This large total is made up of the following items:

For operation, maintenance, zone sanitation and government	$ 5,000,000
For annuity payable to the republic of Panama	250,000
For interest at 3 per cent upon the cost of the canal	12,000,000
For ¾ of 1 per cent per annum for amortization of the investment	3,000,000
Total	$20,250,000

By the end of the first decade of the canal's operation, i. e., by 1925, the tonnage of vessels using the waterway will amount to 17,000,000 net tons per annum, unless the European War should so cripple the international trade of the world as seriously to restrict for a considerable time the volume and rate of increase of the world's commerce. At the present rate of tolls a tonnage of that volume would yield revenues covering all operating and capital expenses. If the rate of tolls that has been established is maintained for ten years and if subsequent reductions in the rate of tolls are conservatively made, it will be possible for the American people to secure from the Panama Canal revenues that will cover out-of-pocket expenses and return to the United States treasury the sum that has been invested in the waterway. This can be done without restricting the usefulness of the canal, and if this policy is followed out it will be possible for the United States, with less burden to the taxpayers of the country, to construct other needed public works.

A scientific code of tonnage rules has been formulated and put into force for the measurement of all vessels using the Panama Canal. Those who have to pay tolls naturally desire and seek to have the tonnage rules so changed as to lessen the amount paid by vessel owners. It is to be hoped that the President and the Secretary of War, who are in charge of the administration of the canal, will resolutely maintain the tonnage rules as they now stand, or will make only such modifications in the rules as may be required to give them greater definiteness.

Among the economic aspects of the Panama Canal to which special attention should be given is that of managing the canal in a business-like manner. It is now being wisely managed. The present policy of charging reasonable tolls upon all vessels, and of applying impartially to all types of merchant vessels a code of tonnage rules so framed as to determine and express the actual capacity available for carrying cargo and for accommodating passengers should be zealously maintained. If this is done the United States will demonstrate to the world that a great government enterprise can be managed in accordance with sound economic principles.

Paper No. 3

OUTLINE OF CANAL ZONE GEOLOGY.

WITH SOME REFERENCE TO ITS BEARING ON CANAL CONSTRUCTION.

By

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TOPOGRAPHIC RELATIONS.

The surface configuration of the Canal Zone embraces two chief types of topography, as follows:

The hill type, well developed in the central and southern parts of the Zone, includes peaks up to 1000 feet (305 meters) in elevation. Below these are ranged irregular ridges and angular hills separated by crooked, unsymmetrical valleys and basins. This topography is most striking in its irregularity and presents some likeness, in its green jungle-covered hills and hollows, to enormous cross-waves at sea.

In building the Panama Railroad, and some of the branch lines for dumpage, the sinuosity and curvature introduced into the tracks in order to avoid the numerous hills, added difficulties to both their construction and operation. The height and steepness of Ancon Hill enabled the rock product, from the quarry there, to be handled by gravity from the blasting face through the crushing plant and onto the cars.

The coastal plain type of land-form, developed principally on the Atlantic side, comprises five groups of relief, which are: (1) coastal swamps, of considerable depth, inland swamps, and alluvial basins; (2) coral flats and coral reefs, which are from a few feet below, to a few feet above high tide level; (3) river flats of alluvium in the lower valleys; (4) bars at and near the mouths of rivers, beaches, sand spits, etc.; (5) remnants of seaward tilted plains, now locally forming low hills.

Surveys through these unhealthful black-mud and green-water swamps were most difficult, as was the construction of the Panama Railroad lines across them. The site of Colon City was once a great tide-level coral flat, and it had to be graded up to 3 or 4 feet (1 meter) above tide-level in order to build the town. The swamp and river-alluvial materials were easily dredged and this facilitated greatly the deepening of the approach channels to both the Atlantic and the Pacific locks.

GENERAL GEOLOGY AND ENGINEERING RELATIONS.

ROCK FORMATIONS.

Within the Canal Zone are about 17 different rock formations and most of these show considerable local variation. Fig. 1 shows the rock succession across the Isthmus. Fig. 2 shows the names and age relations of the different formations.

Bas Obispo Formation.

The Bas Obispo, the oldest formation, was formed of rock fragments and ash blown out of old volcanic vents and later consolidated into andesitic breccia. It outcrops extensively at Bas Obispo and near Old Panama, and small outcrops rise above the alluvium near Miraflores and Diablo Ridge.

About 7000 feet (2134 meters) of the north end of Culebra Cut has been excavated in this formation. It is relatively hard and tenacious, except locally where sheared by faulting. From these faulted places masses of loose rock have fallen, but not enough to be classed as important slides. On the whole, this material has stood fairly well at steep angles. In blasting, it broke out in relatively large fragments and did not weather or wash readily, so that the waste from this section was in greater demand for fills and dams, where maximum stability was necessary, than the more friable rock from other parts.

Las Cascadas Agglomerate.

The Las Cascadas agglomerate also consists of volcanic debris partly consolidated, but much less so than the Bas Obispo formation. It contains large and small subangular fragments in a fine-grained ground-mass of volcanic clay and tuff, and some solidified lava-mud flows, as well as flows and dikes of grayish andesite. It outcrops extensively along the Canal

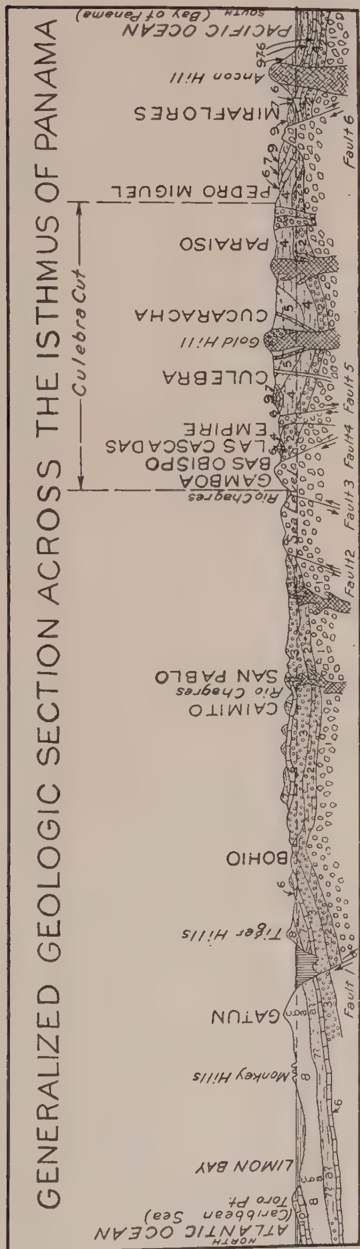
GENERALIZED GEOLOGIC SECTION ACROSS THE ISTHMUS OF PANAMA
Culebra Cut
NORTH
ATLANTIC OCEAN
(Caribbean Sea)
Toro Pt.
LIMON BAY
Monkey Hills
GATUN
Tiger Hills
BOHIO
CAIMITO
Rio Chagres
SAN PABLO
Rio Chagres
GAMBOA
BAS OBISPO
LAS CASCADAS
EMPIRE
CULEBRA
Gold Hill
CUCARACHA
PARAISO
PEDRO MIGUEL
MIRAFLORES
Ancon Hill
PACIFIC OCEAN
SOUTH (Bay of Panama)
Sea Level
Fault 1
Fault 2
Fault 3
Fault 4
Fault 5
Fault 6

Fig. 1.

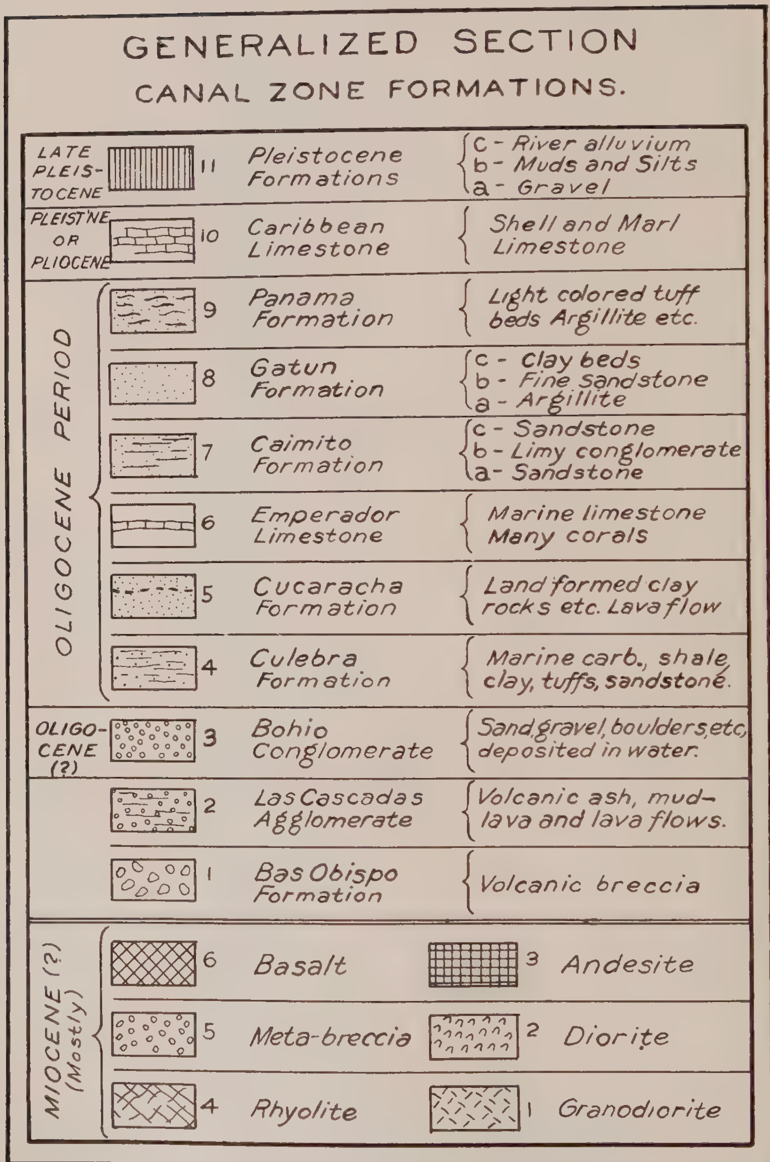
GENERALIZED SECTION
CANAL ZONE FORMATIONS.
LATE PLEIS-TOCENE
11 Pleistocene Formations
c - River alluvium
b - Muds and Silts
a - Gravel
PLEIST'NE OR PLIOCENE
10 Caribbean Limestone
Shell and Marl Limestone
OLIGOCENE PERIOD
9 Panama Formation
Light colored tuff beds Argillite etc.
8 Gatun Formation
c - Clay beds
b - Fine sandstone
a - Argillite
7 Caimito Formation
c - Sandstone
b - Limy conglomerate
a - Sandstone
6 Emperador Limestone
Marine limestone Many corals
5 Cucaracha Formation
Land formed clay rocks etc. Lava flow
4 Culebra Formation
Marine carb., shale, clay, tuffs, sandstone.
OLIGO-CENE (?)
3 Bohio Conglomerate
Sand, gravel, boulders, etc., deposited in water.
2 Las Cascadas Agglomerate
Volcanic ash, mud-lava and lava flows.
1 Bas Obispo Formation
Volcanic breccia
MIOCENE (?) (Mostly)
6 Basalt
3 Andesite
5 Meta-breccia
2 Diorite
4 Rhyolite
1 Granodiorite

Fig. 2.

between Empire and Las Cascadas, and, though presenting many local variations in constitution, yet, on the whole, it is much softer and more friable and was cheaper to drill and blast than the Bas Obispo material. Several very considerable slides developed in it, due chiefly to local areas of weakness and faulting, and to its somewhat clayey character and high ground water content.

Bohio Conglomerate.

The Bohio conglomerate consists of andesitic and dioritic boulders, cobbles, pebbles, and sandy material, arranged in beds which are separated from each other by beds of sandstone and argillite. The formation outcrops extensively in the vicinity of Bohio and near Caimito Junction. Its content of hard boulders renders it somewhat difficult to drill, and lack of jointing causes it to blast less satisfactorily than might be expected from the relatively soft and friable nature of the material that fills its inter-boulder spaces. It was encountered in excavations for the Panama Railroad.

The Culebra Formation.

The Culebra formation contains an upper and a lower member. The lower (a) consists of dark, well laminated beds of soft shales, marls and carbonaceous clays, with some pebbly, sandy, and tufaceous layers and a few thin beds of lignitic shale. The upper member (b) consists of beds and lenses of sandy limestone to calcareous sandstone, 3 to 10 feet thick, separated by partings of dark carbonaceous clays and fine bedded tuffs. Locally, this formation gives off a little natural gas, and in some restricted areas, it shows slightly bituminous shales, so that it is possible that it may be the equivalent of the oil bearing horizon in Garachiné, Darien. The Culebra formation outcrops in Culebra Cut near Culebra and near Paraiso and Pedro Miguel. The upper member, because of its soft and friable nature, drilled and blasted easily and was handled by the steam shovels very economically. In spite of its unstable character, it was relatively less given to sliding than other equally friable formations because: (1) it is well bedded and relatively horizontal, hence there is practically no tendency to slide along bedding planes; (2) it is sandy and drains well, hence does not get as slippery as the more clayey formations;

(3) it seems to be relatively free from chlorite and other slippery mineral particles which are factors of instability and mobility in weak rocks. The thin beds of sandy limestone and limey sandstone, in the lower part of this formation, are fairly resistant to drilling and blasting, and, where they outcrop in the slopes, are strengthening factors against sliding.

Certain local areas of the Culebra formation became heated on exposure to the atmosphere through drilling or blasting. This heating was due to the oxidation of finely divided pyrite. It was thus necessary to test the drill holes in certain areas to determine whether they had become hot and therefore dangerous to load for blasting.

Cucaracha Formation.

In the Curaracha formation many of the big slides developed. The formation consists of a dark green to reddish, slightly indurated, volcanic clay rock of andesitic composition. It is a land-deposited formation, overlying the marine Culebra beds, from which it is separated by 10 to 20 feet (3.05 to 6.1 meters) of slightly consolidated gravel. Locally, it contains lenses of loosely cemented gravel, sandy tufaceous material, and some beds of lignitic shale; the whole cut by basalt dikes. Erosion easily wears away this formation and its outcrops are flats or valleys. An extensive lava-flow is interbedded in it, but, due to excessive jointing, this does not strengthen it much against sliding. The soft, friable and clayey nature of this rock, its high content of water and of slippery chloritic mineral particles, the lignitic shale beds, and the sheared fault zones, are the factors which make it especially subject to slides.

Emperador Limestone.

The Emperador limestone is a light colored, fairly pure limestone and contains many fossil corals. The formation outcrops northwest of Empire, south of Las Cascadas, on the relocated line of the Panama Railroad near San Pablo, near Frijoles, in the swamp southeast of Diablo Ridge and extensively near Alhajuela. It seems to extend over a wide area, and has prospective value as a source of lime and possibly of cement. Locally, it is somewhat hard and tough and is about equal to the Bas Obispo formation in its resistance to drilling and blasting.

Caimito Formation.

The Caimito formation consists of upper and lower sandstone members with a calcareous conglomerate member in between. The sandstone members are soft, argillaceous, and grayish to yellow in color, and locally they weather into somewhat spherical fragments. The calcareous member contains fragments of much decayed basic material which locally gives a bright green stain to small patches of the rock. The formation outcrops at Bald Hill north of Miraflores, extensively at San Pablo and on the relocated line of the Panama Railroad near New Culebra.

These rocks are relatively easy to drill and blast, and the weathered product from the more clayey beds might perhaps be suitable for the manufacture of common brick.

Gatun Formation.

This formation consists of three members: the lower, containing fossiliferous argillites, soft sandstones, and some conglomerate; the middle member, mostly fine, soft sandstone, containing a few fossils; and the upper member, made up of light to creamy-gray colored argillites.

This rock has been used extensively for fills on the relocated line of the Panama Railroad, because of its convenient location and the cheapness with which it could be mined and loaded. Because of its friable quality, however, it could not be used where subject to the scour of a river or of sea waves. The formation is amply firm and solid for wide foundations and its fineness of grain renders it relatively impervious to ground water. It, therefore, makes an excellent foundational site for the Gatun dam and locks.

The Panama Formation.

The Panama formation is a light colored, well bedded tuff with some argillitic material. It outcrops extensively from Miraflores to Panama, and is relatively porous, somewhat jointed, and of a crumbly or friable nature. It is not difficult to drill or blast, and is somewhat too soft for good road metal.

Caribbean Limestone.

The Caribbean limestone is a sandy fragmental limestone, locally a coquina or shell marl. It outcrops at Toro Point, west of Gatun dam, and at the mouth of the Chagres River,

and in most of these places, it forms low bluffs. It is the rock from which Fort San Lorenzo was built, and was quarried from a convenient outcrop on Toro Point for use as a hearting for the breakwater there. Its soft and easily abraded character, however, prevented its use except as core material. The breakwater had to be faced or armored with a much harder, tougher. and more expensive rock taken from Porto Bello.

Pleistocene Formations.

These consist of: (a) swamp formations, black soil and silt, filling old channels to depths of 375 feet (114.3 meters) below present sea level; (b) river gravels up to 10 feet (3.05 meters) above present normal river levels, and old sea beaches 6 to 10 feet (1.83 to 3.05 meters) above present beach level; (c) bars, beaches, and present river alluvium. All of these formations have a distinct bearing on the engineering problems of the Isthmus. The deep swamp formations not only rendered the surveys difficult, but added much to the cost of building railroad fills across them. The river gravels proved very useful for ballasting the road, for local concrete work, and for other purposes. Some of the beaches furnished vast tonnages of sand for construction purposes. Much river sediment had been deposited as bars and shoals which partly obstructed the Atlantic and Pacific entrances to the Canal, and so extensive dredging of the approach channels was necessary.

Igneous Rocks.

The igneous rocks within the Canal Zone, those which cooled from the molten state, belong to six groups. Three of these are shown on the geological section (Fig. 1); the others are in place near the Canal.

Granodiorite is a quartz bearing locally porphyritic rock, a member of the broad group of granite rocks. It is found among the gravels of the Chagres River, so probably outcrops at several places within the Chagres drainage basin. Another rock which may be classed under this heading, is that which forms Cocovi Island in Panama Bay. The rock is strong, fine-grained and would make an excellent building stone.

Diorite, a rock much like granite but with little or no free quartz and with much dark hornblende, is found at Point Farfan opposite Balboa, also among the gravel of the Chagres,

showing that it probably outcrops in the Chagres Valley, and as boulders in the Bohio conglomerate. It is a tough, well-crystallized rock and would do very well for building purposes.

Andesite, a fine-grained, dark colored, hard, tough rock of about the same chemical composition as diorite, is known at a few places in the Canal Zone. Necks and dikes of andesitic rock cut the Las Cascadas agglomerate and the diorite at Point Farfan. Rocks of the same general character form the steep headlands at Porto Bello, and constitute the material quarried, crushed, and transferred to Gatun for use in the concrete work of the locks. Huge blocks of this rock, from the Porto Bello quarry, were transported on lighters and used to armor the breakwater at Toro Point.

The well crystallized character of both the Porto Bello and Point Farfan rock renders them tough and resistant to abrasion by waves; hence they are well suited for breakwater or seawall construction.

Rhyolite, a fine-grained, light colored igneous rock, forms Culebra and Naos Islands, and Ancon Hill. The latter stands about 600 feet (183 meters) above the low lands that nearly surround it, due largely to the hardness of the rhyolitic rock of which it is composed. This rock is very much fissured and jointed, hence was very cheaply quarried and crushed for use in the concrete of the Pacific locks. Its strength and toughness rendered it very suitable for such use, and it also makes a good road metal.

Basalt, a dark, basic, fine-grained rock, forms many cores, dikes, and flows near Empire, Culebra, Pedro Miguel, the top part of Gold Hill, the hills near Paraiso and Rio Grande; it also forms a hill near the Panama Railroad two miles north of Montelirio. In fact, most of the steep hills and ridges within the Canal Zone, except Ancon Hill, are formed of basalt. It is hard and tough, would be excellent for concrete work, and has locally been put to good use in the building of roads. It was proposed to use it to armor the projected new east breakwater at Colon, but the rock was found to be so cut with joints, that it would probably not break out in large enough pieces to resist the abrasion of sea waves. It would serve, however, as the first coat of armor over the cheaper and more easily

abraded hearting or core material, if the whole were faced with large blocks of the Porto Bello rock. It was used to a considerable extent for facing the water level zone of the Gatun dam and it makes an excellent road metal.

Meta-Breccia. Under this heading are classed the metamorphosed tuffs, agglomerates, and breccia masses that form Gold Hill, Contractors Hill, Office Hill (Culebra), the breccia at Paraiso, at Empire, and at other places. Associated with practically all of these breccia masses are basalt dikes. Both the Gold Hill and the Contractors Hill masses have been faulted downwards some hundreds of feet and all the other breccia masses seem bounded by fault contacts. The evidence indicates that they were pushed upward, as somewhat metamorphosed and toughened caps, on top of basalt plugs or cores. They have acted as strengthening pillars to buttress up some of the sliding areas in Culebra Cut.

Lava Mud Flows.

In addition to the igneous rocks above enumerated, there are several consolidated lava-mud flows in the Las Cascadas agglomerate. These locally show columnar structure. On exposure to the atmosphere for a few years they weather and crumble very considerably.

STABILITY OF THE ISTHMIAN LAND.

From the geological evidence, it would seem that the Isthmian land first appeared as an archipelago of islands in a shallow sea, and that perhaps in late Oligocene time land connection between the two continents was established. At four different times, in the long geological periods that followed, the land sank below sea level, except, perhaps, for the higher peaks. In late Pleistocene time it was elevated to several hundred feet above its present level, then it sank to a depth of 6 to 30 feet (1.83 to 9.14 meters) below where it now stands. Very fresh looking old raised sea beaches and other evidence indicate that this latest upward movement began, perhaps, within the last 1000 years.

The geological instability of the land, particularly the last uprise, leads to the question as to whether the Canal is in danger from emergence. If it were a rapid uplift, there would

be some danger, but it seems to have been much lower than 0.03 of a foot (1 centimeter) a year, or 3 feet (1 meter) in 100 years. Dredging could, of course, take care of this, with very little additional expense above the ordinary dredging necessary for the annual upkeep of the Canal. Then, too, there is always the chance that this motion will stop or be reversed into a sinking movement. In conclusion, then, it is quite certain that the Canal is not in any appreciable danger from the geological instability of the Isthmian land.

STRUCTURAL GEOLOGY IN RELATION TO ENGINEERING.

From Gatun, the rocks dip gently northward under the Caribbean. The upper beds of the Gatun formation are relatively impervious, but 500 or 600 feet (152 or 183 meters) below the surface there are coarser beds that might contain some water. If a well, say at Colon, were drilled down to these coarse beds, it might possibly develop artesian conditions, now that Gatun Lake is nearly 80 feet (24.4 meters) higher than Colon.

A downfold, or syncline, of the bedded rocks trends across Culebra Cut near Gold Hill. This brings the stronger limey sandstone beds far below the bottom of the cut for a distance of a mile or more and leaves only the weak argillaceous rocks of the Cucaracha formation to form the slopes of the cut. Hence, this region is the locus of the greatest slides.

The many vertical movements of the Isthmian landmass have broken big fractures or faults in the rocks, and, where these sheared zones trend across the Canal, they are weakening factors in the slopes and help to promote slides.

Jointing and fissuring cause most of the smaller masses of igneous rock to break out in very small pieces when blasted. In getting crushed rock from Ancon quarry, this feature saved the United States hundreds of thousands of dollars in blasting and crushing costs. Lack of such fissuring was one of the reasons why the rock at Porto Bello was more expensive to blast and to crush. The coarse breaking quality of the Porto Bello rock, however, was useful in furnishing strong and heavy material with which to armor the breakwater against sea waves.

For more than a year, certain dikes and flows of hard basalt held back the Cucaracha slide. They seemed large and heavy enough to hold it back permanently, but when the cut was brought to final depth in front of them, the accumulated stresses of the loose material behind the dikes caused them to be sheared off where they had been greatly weakened by cooling cracks, and thus the slide took on renewed action.

Such intruded masses of relatively tough rock, as Gold Hill and Contractors Hill, act as piers and buttresses to strengthen the weak slopes against sliding.

SLIDES.

In Culebra Cut, there are four distinct types of slides: (1) structural breaks and deformations; (2) normal or gravity slides; (3) fault-zone slides, and (4) surface erosion.

Structural Breaks and Deformations.

General Description.—The largest and most important slides developed from structural breaks and deformations. Fortunately, they occurred only near Culebra, in a section of the Cut not much over a mile long. These deformations were first indicated by cracks or fissures, parallel or somewhat oblique to the edge of the Cut, and from a few meters to some hundreds of meters back from it, and from each other. The second stage was a settling or outward tilting of the big blocks cracked off from the solid bank. The front part of each block generally sank, with maximum sinking sometimes amounting to two meters in the outer exposed portion of the front block. The rear part of some of the blocks tilted up to 0.8 meters above the front part of the block behind. The third and last stage consisted in the dropping downward of the block, due to the failure and squashing out of its base. The whole block then disintegrated and sloughed down into the excavation. This last stage ran its course in from a few hours to a few days. The other two stages required months or even years to reach completion. The last two stages were usually accompanied by bulging of the bottom and lower slopes of the cut in front of the moving mass.

Causes.—This type of deformation was due to a primal cause, the unstable geological condition of the materials involved;

and an immediate cause, the over-steepness and height of the slopes, the blasting and other work attributable only to man. The first of these depended on several geological factors, chief among which were: (1) the formations involved were of very soft, weak rocks, comprising massive, partly indurated volcanic clays, very friable bedded tuffs and soft, brittle and slippery lignitic shales; (2) these rocks had been further weakened by faulting and by some joint and bedding planes; (3) an abundance of ground water had invaded this material whenever it was disturbed by movement or fissuring, and this greatly added to its mobility; (4) lignitic shale beds, especially where they dip canalward, were planes of weakness along which there was a strong tendency for the overlying material to slip; (5) the presence of a considerable proportion of chlorite particles in the volcanic clay rocks tended to lubricate the mass. The second or immediate cause was chiefly the over-steepness of the slopes where the banks were high and the rocks weak, and the large percentage of ground water they contained. The vibrations generated by blasts near these high, over-strained banks were also slide-producing factors. The geological conditions were not sufficiently considered in the first estimates and plans for digging Culebra Cut.

Remedies.—For this type of slide there was but one remedy that had utilitarian value under the conditions involved, and that was applied. It consisted in making the slopes less steep by removing material from their upper portions, so that the unbalanced pressure toward the foot of the slope was less than the crushing or deforming strength of the rock involved. Steam shovels terraced back the slopes on either side of the Cut, this relieving somewhat their strained condition. At first sight, it might seem preferable to let the slides come into the excavation until permanent slopes were reached, thus saving the expense of much blasting. But deformations of this kind weakened the rocks far below the bottom of the excavation (see Fig. 3), and this weakened material required a much flatter slope than the angle at which it would have stood before being weakened by deformative movements. Further, as each block or mass crushed down, it generally left behind not a gradual slope, but a steep face 12 to 25 meters (40 to 82 feet) or more high,

which greatly assisted in the generation of other slides. Then there was the temporary obstruction of railway tracks and drainage ditches caused by some of these slides.

Normal or Gravity Slides.

The normal or gravity type of slide was due to several factors. Locally along Culebra Cut, porous material lies on top of relatively impervious clay, shale or igneous rock. Rain and ground-water saturated the porous mass, but were impeded in their downward course by the relatively impervious rock. This caused a muddy, slippery zone to form along the plane of contact between the pervious upper and impervious lower materials. Where this plane sloped excavationward, or where there was thrust or head of pressure toward the excavation

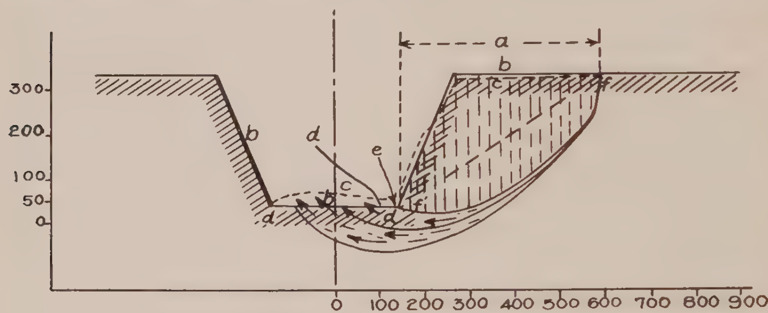

Fig. 3. Form Assumed by Structural Breaks and Deformations.

from higher ground in the rear, a slide of the normal or gravity type generally resulted. Where bedding and joint-planes dip excavationward, they greatly assisted gravity to wedge off rock masses. This type of slide had certain distinguishing features. The rocks were not deformed or weakened below the plane of actual sliding. The sliding material moved off a solid base, and this was not pulled down or squeezed out by the frictional pull. Hence these slides were not as destructive as the break-deformation slides, for they did not weaken the slopes, but disturbed generally only the material which actually moved. Ordinarily, no saving of excavation could be accomplished by removing material from the upper parts of such slides. It was better and cheaper to let them run their course and remove them from the bottom of the Cut. Drainage was

almost the only remedial factor that could be applied to them. The Cucaracha slide, which has been active at intervals since the French Company began operations, was the most troublesome of this type.

Fault-zone Slides.

The third type of slide was that occasioned, primarily, by the weakening effects of sheared fault-zones which cut diagonally across the Canal prism. These were in some cases assisted by a weak layer of rock near the toe of the slope. In these slides, the mass of rock in the acute angle, which the fault-plane makes with the plane of the excavation wall, had in some cases a large over-hang, due to the dip of the fault. This over-hang rested insecurely against the fault-plane, thus throwing an additional strain on the whole block. As the excavation was deepened, this strain increased and, if the base of the block failed, a fault-zone slide resulted.

Two large slides of this type occurred on the east side of the Canal, between Empire and Las Cascadas. In the case of the La Pita Slide (Fig. 4), a strong andesite breccia (d) covered a much weaker volcanic agglomerate and lava-mud flow (e) to a depth of 60 feet (18.29 meters), the whole forming a steep wall 90 feet (27.43 meters) high. A major diagonal fault-plane (a) with an excavationward dip of 65°, and a minor fault-plane normal to the horizontal and to the axes of the Canal, were the chief weakening factors. Water from a diversion ditch at (c) seeped down along the fault-plane, and helped soften the already weak volcanic agglomerate (e) until it failed. The final result was that 20,000 cubic yards (15,290 cu. meters) of rock crushed down and had to be removed. Another slide a little north of this let down 300,000 cubic yards (229,350 cu. meters) under practically similar conditions.

The fault-zone type of slide, unlike the others, occurred in rocks strong enough to stand at a steep slope but for the weakening effects of diagonal, canalward sloping faults, which left overhanging parts of large rock masses resting insecurely against slippery fault-planes. Slides of this character were not common and the only remedy for them was to lessen the slopes in the vicinity of these fault-zones, and, where practicable, to prevent excessive water from seeping into them.

Fig. 4. La Pita Slide between Empire and Las Cascadas.

There might be cases where it would pay to reinforce such weak zones with steel and concrete work, to prevent initial motion, but no such case came to notice in the Canal Zone work.

Sliding Due to Erosion or Wash.

The soft and easily weathered rocks of Culebra Cut, where steep and unprotected by vegetation, are greatly trenched and washed by heavy rains. Each heavy rain removes the disintegrated soil from the steep sides of the excavation, leaving fresh surfaces exposed for further weathering action. It is estimated that the sediment washed into Culebra Cut in this way is something like 65,000 cubic yards (50,000 cu. meters). Fortunately the luxurious growth of vegetation, which characterizes the region, provides a remedy. These slopes will suffer relatively little erosion when fully carpeted with grass and shrubs. Such vegetation will have no effect on the large slides, but it will minimize the wash from heavy tropical rains.

Another erosion problem, where the rocks are soft, results from the wash of steamers. Any protective covering, used to obviate this, will have to be designed with some understanding of the geological conditions of the rocks which it is to protect. For instance, the rocks will swell somewhat with oxidation, and they will crumble a little wherever ground water can leach out their soluble salts. There will also be some slight adjustive movements, as time goes on, created by the new conditions of rock pressure. All of these movements will be different, as the character of the rock varies from place to place.

Of all the incidents that grew out of the peculiar geological conditions encountered in canal construction, perhaps none attracted wider public attention than the slides. It may be well then to state in conclusion that slides which may require considerable dredging are likely to continue for the first few years of canal operation. They will, however, not be sufficiently large to endanger traffic passing through the canal, nor to block it for any considerable period, and they do not menace in any way the ultimate utility of the canal.

Paper No. 4

SANITATION IN THE PANAMA CANAL ZONE.

By

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I. PERIOD OF THE FRENCH CANAL COMPANY.

When the French undertook the construction of the Panama Canal in 1881, the Isthmus of Panama had been known for years as the ''pest hole of the world'', and it fully deserved this reputation. Yellow fever had become endemic, and whenever there was a fresh importation of non-immunes, as upon the arrival of Colombian troops from the mountainous regions of that country, an extensive epidemic would occur.

Dr. Wilfred Nelson, in his book entitled ''Five Years in Panama''(1)* states that when he arrived in Panama in 1880, the Dean of the Medical Faculty at that place, in describing the climate, said to him ''First you have the wet season lasting from about the 15th of April to the 15th of December, when people die of yellow fever in four or five days. Next you have the dry season from December 15th to April 15th, when people die of pernicious fever in from twenty-four to thirty-six hours''. Dr. Nelson says that five years as a practitioner of medicine at Panama amply confirms this view of the climate.

While yellow fever was the gravest endemic disease, as far as the death rate was concerned, malaria was the great cause of invaliding. During the period of construction of the Panama Railroad it was stated that no one escaped infection by this latter disease, and it was considered impossible to recover fully from it while living on the Isthmus.

When the French began their work, nothing was known of the mode of transmission of malaria and yellow fever, and

*(1) Refers to serial number of reference in the Bibliography.

hence nothing was done along the line of prevention for these diseases. Indeed, so far as records show, there was no preparatory work of any sort with a view of protecting employees from disease.

A splendid system of hospitals was erected at both ends of the Canal, and money was lavishly spent for this purpose. It is stated that the buildings of Ancon Hospital, with a capacity of about 500 patients, cost, together with the laying out of the grounds, $6,500,000. The wards were of the pavilion type and admirably adapted for their purposes, so far as location, arrangement and ventilation were concerned, but the supply of water was limited, there were no bath rooms nor water closets, nor were the buildings screened in any way.

The administration of the hospital was bad. It was run by the nursing sisters, who, by the terms of their contract, were allowed to charge one dollar per day for each employee. As this rate was higher than the actual rate of pay of most of the laboring classes, necessarily very few of these applied for admission. Not knowing that malaria and yellow fever were transmitted by mosquitoes, the hospital physicians placed the bed legs in pans of water to keep out ants. These pans of water became breeding places for mosquitoes in the wards, so that all the conditions were present for the transmission from one patient to another of yellow fever and malaria, and other mosquito-borne diseases. Thus the hospital instead of being a place of safety became a source of great danger to the occupants.

The arrival of large bodies of non-immune employees on the Isthmus was followed by severe outbreaks of malaria and yellow fever, because of which it became almost impossible to carry on the work. In the month of September, 1884, out of a total force of 18,647 employees, the Canal company buried 654 officers and men. During the period from 1881 to 1889, covering the operations of the first French Canal Company, 1026 employees died in Ancon Hospital from yellow fever. It is estimated by Col. Gorgas(2) that fully as many died outside of the hospital from the same cause. During this period the force of white employees, who were alone susceptible, never exceeded 2500 men, and most of the time was far below that figure.

During the same period 5527 employees died in Ancon Hospital from various causes; it is estimated by competent authorities that for each employee who died in hospital, two died outside of it, so that the total number of deaths of employees in eight years would be about 16,500 (Col. Gorgas places it at 22,000); and this out of a force the average maximum of which, for the eight years, was 13,055.

II. CONSTRUCTION PERIOD UNDER THE AMERICAN ISTHMIAN CANAL COMMISSION.

When the Americans undertook the construction of the Panama Canal in 1904, one of the first steps taken was to send to the Isthmus a committee of sanitary experts headed by Col. W. C. Gorgas, Medical Corps of the United States Army, who had just earned a world-wide reputation as Chief Sanitary Officer at Havana, in freeing that city and Cuba of yellow fever where it had been endemic for 400 years. This committee went carefully into the work of making plans for the control and prevention of disease, without which a successful outcome for the Canal construction would have been impossible.

The principal diseases to be combatted were malaria and yellow fever, the former by far the more important from the point of view of the actual disability to be anticipated from its operation, but the latter pre-eminent, on account of the demoralization of the force which would necessarily result from the large death rate which would occur.

There were, however, other tropical and general diseases prevailing, which were of no little importance. Among these were beri-beri, small-pox, dysentery, and typhoid fever.

Col. Gorgas, from his experience gained in Havana, had evolved what was practically a new idea in sanitation, and which was destined to have a far-reaching effect both in securing results and in effecting economy in costs.(3) In Havana he had noticed that after two years in time, and the expenditure of a great deal of money, he had made Havana a "clean city", but that nevertheless not only did yellow fever continue, but the number of cases steadily increased. After it was discovered that yellow fever was transmitted by the mosquito, and solely by the *Stegomyia fasciata* mosquito, he directed his

preventive measures entirely against that mosquito and the disease disappeared. The new idea was that in preventive measures we should not waste our efforts and money in "shot-gun" prescriptions, for "general sanitation", but direct them against the ascertained agencies which influence directly the transmission of the disease in question.

As in fighting yellow fever the *Stegomyia fasciata* (*Aedes colopus*) was the only enemy, and in malaria certain *Anopheline* mosquitoes, no money was wasted in fighting other than the disease-carrying species of mosquitoes.

By studying the life history and habits of the infectious species, information was acquired of great importance from an economical point of view. For instance, near a settlement there might be a large pond or marsh in which mosquitoes were breeding and which it would be very expensive to drain or treat; if it were found that *Anophelines* did not breed in it, no action would be necessary so far as malaria was concerned. Or, it having been ascertained that the flight of *Anophelines* was usually against the wind, it might be unnecessary to care for a breeding place on the windward side of a settlement.

The organization proposed by Col. Gorgas for the Sanitary Department included three divisions, the quarantine division, the hospital division, and the sanitary division proper.

The **quarantine division** had entire charge of quarantine matters on both sides of the Isthmus.

The **hospital division** had charge of the care of the sick and included a large hospital at Ancon on the Pacific side, with a capacity of 1600 beds, and another on the Atlantic side at Colon, with a capacity of about 500 beds, an asylum for the insane, and another for the care of lepers at Miraflores, and later at Palo Seco. The Canal Zone itself was divided into a number of districts, in each of which a small hospital or sick-camp was provided, under the care of a physician and staff of attendants, their purpose being to give emergency treatment and to care for patients who might not require more than one or two days in the hospital.

A hospital train, with a specially fitted hospital car was provided which crossed the Isthmus once or twice a day, taking up the sick at each station for transmission to the hospital.

The **sanitary division** was divided into three sections, the Health Office of Panama, the Health Office of Colon, and the Canal Zone section.

The Health Officers of Panama and Colon performed the usual duties of Health Officers elsewhere, and, in addition, had charge of street cleaning and garbage removal. A code of sanitary regulations was drawn up and the Health Officers took charge of their enforcement. The cities were divided into districts, each in charge of a sanitary inspector. In sanitary matters the Canal Zone was under the charge of a Chief Sanitary Inspector and Assistant Chief Sanitary Inspector. It was divided into districts, each in charge of one or more sanitary inspectors with a corps of assistants. There were also two division inspectors and an inspector-entomologist.

YELLOW FEVER.

When the force for the construction of the Canal began to arrive, in June, 1904, yellow fever was prevailing sporadically, as it always did during the intervals of the severe epidemic outbreaks which followed the introduction of large numbers of non-immunes.

The water supplies of the Canal Zone and the terminal cities consisted entirely of rain-water, which was stored up through the dry season in tanks, cisterns and receptacles of all sorts, affording ideal breeding places for the yellow fever mosquitoes which were everywhere present in vast numbers.

The first thing to be done, therefore, was to do away with these water containers, by providing an abundant supply of piped water with sewers to carry it off, and this work was undertaken immediately after the first Commission took charge.

At the same time provision was made for paving the streets and thus disposing of the thousands of puddles of water in streets and patios, in which mosquito breeding was going on.

Yellow fever did not cause any serious alarm until the close of the year 1904, when the number of cases suddenly increased from a maximum of two cases in November to six cases in December, and nineteen in January of 1905. From this time there was a steady increase until June, in which month there were sixty-two cases and nineteen deaths.

By this time a panic had begun to seize the employees, and the number who left the Isthmus on account of yellow fever was limited only by the ability of the outgoing boats to carry them away.

The measures taken for the control of the disease were aimed directly against the *Stegomyia fasciata* mosquito, now known to be the only transmitter of the disease; they were grouped under the following heads:

(1) Elimination of breeding places.
(2) Destruction of infected mosquitoes.
(3) Preventing yellow fever mosquitoes from becoming infected, by screening the patient in the infectious stage.

The terminal cities and the Canal Zone were divided into districts, with a sanitary inspector in charge of each, and a house to house inspection made to discover possible cases of yellow fever as early as possible. Physicians and all those concerned were required, under penalty, to report immediately all suspicious cases, and as the number of cases became less, a reward was offered for each case reported.

Under the first heading the measures taken were:—the introduction of a piped water supply doing away with the necessity for keeping water containers about the premises, the prohibition of the use of water containers within one hundred yards of a piped water supply, and the proper protection of all water containers where conditions required their continued use. Pools, cisterns, and cess-pools were oiled once a week.

When water barrels were used they were screened in the following manner: The top of each was covered with 18-mesh copper wire; upon the center of this was placed a square foot of one-fourth inch mesh wire, to protect the finer screening, and over this was placed a wooden cover with a hole in the center six inches square, to permit introduction of the water; the top was then nailed firmly in place and a spigot inserted near the bottom. (Figure 1.)

For the destruction of infected mosquitoes, the most important measure was the prompt fumigation of the room in which the case of yellow fever occurred, followed by the fumigation

of the entire house and of the adjoining houses. In Panama it became necessary finally to fumigate all the houses in the city, and this was done several times. The methods of fumigation are described under "Malaria".

Fig. 1. Screened Water Barrel.

Under the third heading were measures to screen promptly the yellow fever case, either in his own quarters or in hospital, and the permanent screening of all quarters in the Canal Zone. Yellow fever cases, and all suspicious cases which might be yellow fever, were removed to the hospital, and isolated in mosquito-proof rooms. In screening the patient in hospital or at

home, a portable yellow fever cage was often used as shown in the illustration. (Figure 2.)

All these measures vigorously carried out soon began to show marked success. After June, the number of new cases steadily decreased, and the last case occurred in December of 1905.

Fig. 2. Portable Yellow Fever Cage.

In May, 1906, another case was reported in Colon. It was officially diagnosed as yellow fever but as to its true nature there is much doubt. With this exception, not a single case of yellow fever has originated on the Isthmus since December, 1905. Occasional cases have been introduced from without, but there has been no spread of the disease.

At first it was thought that the preventive means adopted under the last two headings would be the most effective, and

theoretically they should be sufficient of themselves to control the disease; practically they failed to do so. In Panama it was found that several months after these measures had been in force the disease continued unabated. This was probably because a few infected mosquitoes escaped each time fumigation was done, and because there were probably some very mild cases which escaped notice and permitted the mosquitoes to become infected.

Col. Gorgas is of the opinion that the reduction of the number of *stegomyia* by elimination of breeding places is the all-important factor, and that when this number in any infected locality is reduced below a certain unknown point, which Col. Gorgas calls the "yellow fever point", the disease will cease abruptly. ([4]) He states that when the disease disappeared on the Isthmus in December, 1905, there were still present in Panama a large number of non-immunes, a few *stegomyia* mosquitoes, and that there had been recent cases of yellow fever to infect these mosquitoes, yet the disease disappeared abruptly. He explains these facts by stating that when the number of *stegomyia* mosquitoes is reduced below a certain point, the chances of any one of the females biting a case of yellow fever in the infectious period (which lasts only three days), and then living long enough to itself become infectious (twelve days), and then biting a non-immune (which class in tropical cities is always only a small percentage of the total population), are so slight as to be negligible.

In Panama it took noticeably longer to control yellow fever than it did in Havana;—in Panama, sixteen months; in Havana, about eight months. This discrepancy is explained by Col. Gorgas, who states that at the time the mosquito theory for the prevention of yellow fever was put into operation in Havana, they had already developed there a perfect sanitary machine which was quickly put in commission and effective, whereas in Panama the force had to be very slowly organized under great difficulties before it became effective in operation.

MALARIA.

While yellow fever was thus entirely eliminated, the same was not true of malaria. This, as I have stated, was the disease

of most importance, on account of the tremendous disability caused by it. Col. Gorgas says in one of his papers: "Malaria in the tropics is by far the most important disease to which tropical populations are subject, either military or civil. While the percentage of fatalities is not nearly so great as from some other tropical diseases, the amount of incapacity caused by malaria is very much greater than that due to all other diseases combined. I was very much impressed with this at Santiago. While we had more deaths from yellow fever and typhoid fever than from malaria, the latter was the disease that prostrated our splendid little army. About the beginning of August there were very few individuals that were not suffering from fever, and the army as a whole was scarcely able to move. The mental depression caused by this general sickness can hardly be appreciated by any one who did not see it, and against a fresh enemy of greatly inferior strength our army of that time would have been entirely helpless.

"Panama, I suppose, is as favorable a place for the development of malaria as could be found. The towns of Colon and Panama, at the terminals of the Canal, are not large enough to do away with the breeding of *Anopheles;* that is, *Anopheles* breeding in the suburbs can very well travel to the centers of these towns, and the population living along the Canal in little villages a mile or two apart, between Colon and Panama, are ideally situated for the development of malaria. About one-third of the Canal runs through a low alluvial and marshy plain, and the other two-thirds pass through a hilly and mountainous country. Along the banks of the little rivulets, which run in every direction, the *Anopheles* breed just about as well as in the marshy level country, and the very general infection of the population by malaria, causes most of the *Anopheles* near human habitations to become infected.

"We knew from the experience of our predecessors on the Isthmus that malaria would be our greatest trouble, and we did what we could toward correcting the conditions. Our greatest endeavor has been toward draining the localities near all towns and dwellings, so as to make the ground as dry as possible, and in order to leave as few breeding places as possible for the mosquitoes. In places that could not be drained, oil was used very freely.

"With a large body of laborers, such as we have here, I think an equally important measure is the giving of prophylactic doses of quinine. We also screened as many of the houses as possible and influenced all inhabitants to use mosquito-bars. These measures, followed up persistently, have had a great effect in reducing the malaria".

At this time investigation showed that about seventy percent of the people living on the Zone had the organism of malaria present in their blood, in other words, were active carriers of that disease.

Malaria being a disease which is transmitted only by *Anophelines*, which are country-bred mosquitoes, the measures taken against them were principally confined to country districts and the suburban sections of the terminal cities.

The methods used may be classified as follows:

(1) Elimination of breeding places by filling, drainage, (tile and surface), introduction of sea-water into fresh water pools, trimming and cleaning of banks of streams, cutting of brush and grass, etc.

(2) Destruction of larvae by oiling, poisoning with larvacide, and the introduction of small fish of the species which feed on larvae.

(3) Destruction of adults by catching-tubes, by traps, and by fumigation.

(4) Protecting man from the bites of mosquitoes by screening.

(5) Segregation of employees, that is, locating the dwellings of non-immunes far apart from the native villages, the inhabitants of which form reservoirs from which mosquitoes obtain their infection.

(6) Immunization by use of quinine, that is, quinine prophylaxis.

ELIMINATION OF BREEDING PLACES.

Filling. This of course is the most satisfactory way of eliminating a breeding place, as it is a permanent cure, but it was often impracticable on account of the expense involved; however, large areas were filled with waste from the cuts or

from hydraulic dredging and these filled areas increased in value far beyond the cost of the fill.

Drainage. Simple unlined ditches had often to be used during the construction period of the work as temporary measures, but they required constant attention and were therefore expensive. Sub-soil or tile drains were very satisfactory in certain situations, but in time they also frequently became obstructed by roots and silt, and required to be opened up for repairs.

Concrete lined ditches are very satisfactory, and while their first cost is large, their maintenance is very inexpensive. A number of different types have been tried on the Isthmus, and the general tendency has been to make them simpler and less costly. Among the forms at present in use are,—those made of old French roof tile covered by a thin layer of concrete, chicken wire covered with concrete, and a rubble made of stones picked up in the vicinity wherever stones were plentiful. In all these forms, it is necessary wherever there is much slope to use key walls at more or less frequent intervals, to prevent the concrete from washing out.

Introduction of Sea Water. The larvae and pupae of *Anopheline* mosquitoes cannot live in sea water; therefore its introduction into fresh-water pools has been found very effective, where the sea water could be introduced in sufficient quantity to make and keep the pool strongly saline, and flush it out with the rise and fall of the tide.

Cleaning Banks of Streams and Pools. It has been found that, where pockets formed in the banks of streams and pools, or where these are obstructed by vegetation, *Anopheline* mosquitoes breed freely. For this reason pockets are filled or cut away and the banks of the stream cleared of brush and grass, and cut down vertically if practicable, so as to obtain the benefit of wave action, and also allow access of the small fish which eat the larvae.

Along unlined drainage ditches the best method of getting rid of grass and brush is by burning; for this purpose a Myers barrel-pump is used. A fire is started at the windward end of the ditch and is kept in progress by spraying crude oil upon and a little in advance of the fire, toward leeward. The barrel

pump is fitted with about fifty feet (15 meters) of rubber hose, at the end of which there is inserted about six feet (1.8 meters) of one-half inch (1.27 centimeters) metal pipe with a spray nozzle at the end. (Figure 3.)

Fig. 3. Burning Grass from Side of Ditch, Crude Oil used as Fuel.

Experience has shown that when the sides and borders of ditches are thus burned and then treated frequently with crude oil, vegetation does not grow again for a long time and the stability of the ditch against washing by rains is greatly increased. (Figure 4 and Figure 5 in contrast.)

Cutting of Brush and Grass. Brush and high grass not only act as a protection to the adult mosquitoes, but prevent the evaporation of small pools of water, and hide these from the inspector; they also hide receptacles of all kinds, which may hold sufficient water for breeding purposes; therefore, grass and brush should be cut away for at least 500 yards (457 meters) from the nearest quarters.

Fig. 4. Condition of Ditch Two Months after Grass Burning.

Destruction of Larvae.

Oiling of pools, ditches, etc., with crude oil so as to form a surface film, which cuts off access to air for the mosquito larvae, is extensively used. At one time we were using 65,000 gallons (246,053 liters) of oil per month for this purpose. Many devices have been used for the purpose of distributing the oil.

For small permanent streams and running ditches the most common device is an automatic drip-can made from an ordinary

garbage can, in the side of which is cut a small opening, about three inches (7.6 centimeters) above the bottom, two inches (5 centimeters) in width and three-eighths of an inch (0.95 centimeter) high; into this opening is soldered a flat spout of tin, one and three-fourth inches (4.5 centimeters) wide, one-fourth inch (0.64 centimeter) high, and three inches (7.6 centimeters)

Fig. 5. Ditch, Cleaned by Hand, Two Months after Removing Grass.

long, and in the spout is placed a lamp wick leading into the oil. The bottom of the can up to within one inch of the wick is filled with water, which serves as a catch basin for gross impurities which would otherwise clog the wick. (Figure 6.)

As the oil which we use here is rather thick, it is convenient to cut or thin it by adding five to ten per cent of "larvacide" or kerosene oil. The drip-can is placed on a board at

the head of the ditch or stream and at a height of three or four feet (about one meter) above the surface of the water and so arranged that there will be a constant dripping of oil upon the surface of the water. These drip-cans are visited once or twice a week by an inspector who keeps them full and notes whether they are dripping at the proper rate.

Fig. 6. Sanitary Drip-Barrel. Drips Mosquito Oil Automatically.

For small pools the oil is thickly spread by an ordinary garden sprinkling can. In other places a "Myers knapsack" and spray pump is used. (Figure 7.)

For oiling ditches along roads, Sanitary Inspector Trask has devised a sprinkling cart with a movable arm which can be raised or lowered, and extends over the ditch. When the roads

are not too soft this device is a great economizer of time and labor. (Figure 8.)

Another device which has been found useful is to take a large handful of waste, saturate it with oil, tie to a stone and anchor it in a ditch or drain.

Fig. 7. Application of Larvacide (Mosquito Oil) by use of Knapsack Sprayer.

Where large bodies of water which have been oiled, are subjected to strong winds, the oil film is often blown off to one side, and to prevent this dispersion of the film, pieces of wood or plank are used, anchored in place on the windward side.

Small fish, especially top minnows, which feed upon larvae, have been found useful in reducing their numbers in places where the oil cannot be used. For some unknown reason, fish do not seem to be as effective for this purpose on the Isthmus as they are elsewhere. Of course, in order that they should be useful at all it is necessary that the larvae should be accessible. Where algae and other forms of vegetation are abundant, it is impossible for the fish to get at them, and under such circum-

Fig. 8. Wheeled Ditch Oiler.

stances other measures must be resorted to, or the algae and vegetation must be cleared away.

Destruction of Adults.

Where large numbers of adult mosquitoes have been found in quarters, it was the custom to destroy them by fumigation, with pyrethrum or sulphur. Sulphur was used in a proportion of two pounds (907.2 grams) per one thousand cubic feet (28.32 cubic meters) of air space, with an exposure to the fumes of about two hours; pyrethrum, about two pounds (907.2 grams) to the thousand cubic feet (28.32 cubic meters) of air space, with an exposure of four hours, was equally effective.

When pyrethrum is used, many mosquitoes are merely

stunned, and it is necessary to sweep them up after the fumigation and burn them.

Latterly, the actual catching of mosquitoes, in quarters where malaria prevails, has been found increasingly effective and fumigation is seldom resorted to. The catching is either done by hand, using tubes, or by traps. The tubes used are the

Fig. 9. Mosquito Trap under Eaves of Labor Barrack.

ordinary glass cylindrical tubes about one inch in diameter, containing a number of rubber bands which have been dissolved by chloroform; over these is placed some absorbent cotton, then a disc of blotting paper, and the mouth of the tube closed by a cork. To catch the mosquito, the cork is removed and the tube placed over the mosquito, which is killed by the fumes of the chloroform and falls into the tube. Catching is done in the dark corners with the aid of a small acetylene hand-lamp.

Recently a very excellent type of mosquito trap has been invented by Mr. Bath, Sanitary Inspector. This trap which is shown in the illustration is placed under the eaves of the quarters, over an opening cut through the screen, usually on the leeward side of the house, and is very effective. (Figure 9.)

Screening.

All the quarters in the Canal Zone are thoroughly screened with eighteen mesh copper wire screening. As a general rule verandas are screened, so that the doors and windows proper are left open. In the veranda there are as few doors as possible, and they are made of screening and open outward. This method of protecting man from mosquito bites by screening the house is far more effective than is the use of mosquito bars, which on the narrow beds ordinarily used, allows the occupants to come in contact with the netting and be bitten by the mosquitoes on it. (Figure 10.)

Segregation.

This is a very important measure, inasmuch as it separates the non-immune population from the natives who serve as reservoirs of malaria. In the Canal Zone it has been carried out as far as practicable, but has not occupied as prominent a position as have the other measures referred to.

Quinine Prophylaxis.

In order to supplement the other measures, and under conditions where they may not be applicable, the use of quinine as a prophylactic measure in doses of two or three grains (0.13 or 0.19 grams), two or three times a day, has been very effective. Some good observers are disposed to question the utility of quinine for this purpose, claiming that those who take it acquire an immunity to quinine which prevents its effective use when they do become infected with malaria. While no authoritative comprehensive tests have been made, the weight of our experience on the Canal Zone is in favor of the effectiveness of quinine prophylaxis.

Dr. H. R. Carter, formerly Director of Hospitals here, and an unquestioned authority upon tropical diseases, especially malaria, states that he has again and again seen a rapid fall in the incidence of malaria after the use of quinine prophylaxis in an infected camp.(5) He states that the more intelligent class

Fig. 10. Screened House.

of white Americans, who have used quinine prophylaxis when malaria was very prevalent, always ask for it again when a new outbreak occurs, thus showing their faith in its efficacy. Certainly large quantities of quinine have been used for the purpose. The largest issue of quinine on the Zone in one year equalled 3,148.05 pounds (1,427.95 kilograms).

Use of Larvacide.

In treating water to destroy mosquito larvae, it frequently happens that oil cannot be effectively applied; particularly is this the case where there is much vegetation in the water, preventing the spread of the film. Again, in the case of small collections of water, and pockets along the edge of streams, other measures are frequently more useful. In such instances we use a substance which diffuses itself through the water in the form of an emulsion, and is poisonous to the larvae. For this purpose "Phinotas" oil was used at first, and later we began to make on the Isthmus a similar preparation for our own use and known as "larvacide".

It is prepared from crude carbolic acid, rosin and caustic soda. The crude carbolic acid must contain not less than 15 per cent of tar acids, and be of a specific gravity not greater than 0.97.

To 150 gallons (568 liters) of crude carbolic acid is added 200 pounds (91 kilograms) of powdered rosin, and the mixture is heated to a temperature of 212 degrees Fahrenheit (100° Centigrade), until a perfectly uniform liquid is formed; 30 pounds (13.6 kilograms) of soda dissolved in about six gallons (22.7 liters) of water is then added and the mixture maintained at the boiling point until a sample of the solution immediately emulsifies with water. The mixture must be stirred briskly throughout the process. This larvacide in a one to 1000 emulsion will kill mosquito larvae in one to five minutes and in a one to 5000 emulsion it will kill them in half an hour.

The larvacide is also a cheap and valuable disinfectant in a one percent solution.

Its only defect appears to be that its efficacy is impaired by exposure to air, and that it is rather expensive, costing about twenty cents per gallon (per 3.79 liters).

For killing larvae, larvacide is used in a ten percent emulsion, which is sprinkled upon the water by an ordinary garden sprinkler or spread upon it with a Myers knapsack-sprayer, in such quantity as to form a solution of about one to 2000 with the water to be treated. It spreads rapidly through the water, both laterally and vertically, and kills all the larvae with which it comes in contact. It appears to be just as effective in sea

water as in fresh water; its action, however, is somewhat different; in sea water it diffuses laterally, while in fresh water the diffusion is downward. (6)

PLAGUE.

The geographical situation of the Isthmus of Panama renders it particularly susceptible to plague infection, and very important as a point of plague distribution, should it ever gain a foothold there.

Ever since American occupation, and before that time, we have been constantly threatened from plague centers on both sides of the Isthmus, which are in frequent and close communication with our ports. Since plague first gained its foothold on the Pacific Coast of South America, in 1902, it has been gradually creeping up the coast until now practically all the ports of Peru and Ecuador are infected and we have it within three days' sail of us, and epidemic, at Guayaquil, Esmeraldas, and Manta. On the Atlantic side, at this writing, it is in Caracas and at La Guayra, its port, the latter within three days' sail of us. It has also prevailed recently at Curaçao, Trinidad, Porto Rico, Santiago, and New Orleans.

It is to be understood that plague is primarily a disease of rats; it only secondarily occurs in man; the infection is conveyed from the rat to man through fleas which have bitten an infected rat and subsequently bitten a man. It is also conveyed, though not so frequently, by infected articles of cargo, and by man himself, though it is directly contagious from man to man probably only in pneumonic cases. Both men and fomites are ordinarily infective only through the fleas which they harbor.

The measures taken for the protection of the Isthmus have been under two headings: first, keeping plague out by means of rigid quarantine; second, putting the ports into such condition as to make it difficult or impossible for it to spread should it be introduced. So far, these measures have been very successful.

Only two cases of plague have originated in the Zone. The first of these occurred in June, 1905, in the person of a West Indian negro who lived in La Boca and worked upon the docks

there; he had not left the Isthmus for three months previously, and must therefore have contracted the disease here. The case was promptly recognized and isolated, and the town immediately placed under the direct charge of the Chief Quarantine Officer, who took active measures for the fumigation and disinfection of the infected area, destruction of rats, and the cleaning up of rat-harbors and sources of rat food; the town was also quarantined.

These measures were entirely successful. The rats caught in the infected area were examined and a few were found to be plague infected.

In August of the same year a second case occurred, in a negro resident of Ancon, working at La Boca. The same measures were used in this case, and since that time no other cases have developed on the Isthmus. Though one or two cases have been brought in from the outside, there was no spread of the disease.

The measures taken to keep out the disease consisted in fumigation and destroying rats at the port of departure, careful inspection at the port of arrival, and a second fumigation, if coming from an infected port; inspection of passengers at the port of arrival, and detention and isolation of all suspicious cases. At the port the ship is fended off and rat guards are used to prevent possibly infected rats from getting ashore.

The building regulations in the terminal ports require that all buildings shall be made rat-proof as soon as possible; houses must be either raised three feet above the ground and built with a single wall, or, if upon the ground, must have a concrete floor with concrete foundation extending at least twelve inches (0.3 meter) below the surface and nine inches (0.23 meter) above the floor; all walls to be single.

In addition, steps are taken to destroy all breeding places for rats, and to starve them out by putting food beyond their reach.

For the latter purpose, garbage cans are required to be kept covered, grain bins lined with metal, stables, etc., to be kept clean.

Rats are destroyed as far as possible by the free use of traps and poisons.

All piers, docks, and wharves are required to be of concrete and iron, or other approved rat-proof construction.

TYPHOID FEVER AND DYSENTERY.

Typhoid fever and dysentery were both prevalent on the Isthmus when we took charge. In 1907 the admission rate for typhoid fever among employees was 14.45 per thousand; in 1913, it was 0.67. For dysentery the admission rate in 1907 was 13.33, and in 1913, 2.07. The most important measures in the control of these diseases have been furnishing an abundant supply of pure water and protecting food from infection.

Reservoirs with piped water were promptly established all over the Isthmus, and, where there was any question as to the purity of the water, distilled water for drinking purposes was furnished in addition.

The Sanitary Department was, until 1912, charged with the duty of testing and making reports on the purity of the water; since that time the Department of Municipal Engineering has had charge of this work. The water sheds of all the reservoirs are fenced off and patrolled; no one is allowed to live upon the water shed, nor is any hunting or other trespass allowed thereon.

The reservoirs are inspected at regular intervals, and when it becomes necessary to allow surplus water to escape, it is drawn off near the bottom; the supply for distribution being drawn from the pure water near the surface.

A system of mechanical filtration, combined with aeration and precipitation, and followed by chlorine treatment, is in use. Samples of filtered and of unfiltered water are examined bacteriologically every day, and a complete chemical, microscopical and bacteriological examination is made once a month; reports of this examination are submitted to the Chief Health Officer for his comment before being sent to the Governor.

Where distilled water is used, the distillate is examined at its exit from the condenser, as well as in the delivery carts.

Flies being regarded as an important means of transmission of these diseases, every effort is made to prevent their breeding and to destroy them, for which purpose garbage cans are emptied and disinfected daily, and the contents are burned.

Stable manure, as being one of the most important sources of fly breeding, is disposed of by burning, burying, or dumping at a sufficient distance from the community. In every district there is an improvised crematory, where garbage and manure are burned; this is made of railroad iron, covered by a rough shelter for protection from the rain.

All kitchens and eating places are carefully screened to keep out flies, and traps are used for catching them when they get in.

In all permanent and semi-permanent camps, range closets, with water carriage, are used. In temporary camps either pit or pail closets are installed. Both these classes of closets are made fly-proof and regularly treated with crude oil or larvacide to destroy any fly larvae which may be present.

PNEUMONIA.

About a year and one-half after the work on the Canal had been inaugurated, pneumonia became very prevalent among the negro laborers, and continued to prevail from the fall of 1905 until the fall of 1907, greatly increasing the mortality among the employees.

The causes of this undue prevalence of pneumonia were carefully investigated by a Board appointed for the purpose. The Board found that the disease was far more prevalent among new arrivals on the Isthmus than among those who had been there for some time, being four and one-half times as frequent among those who had been less than three months on the Isthmus, as among those who had been there more than three months. The Board attributed this largely to the fact that influenza was prevailing in epidemic form and new arrivals, having no acquired immunity to this disease or to pneumonia, promptly fell victims to it, and their resisting power being low, owing to their scant food supply before they came, the fatality rate was unduly high. The mortality rate from this cause among negro employees in 1906 was 19.06 per thousand; in 1907, 11.00; in 1908, 2.60; and in 1913, 1.03.

The sudden fall in the mortality for pneumonia in 1908 is attributed by Col. Gorgas to the fact that in 1907 there was a radical change in the housing conditions among the negro

laborers; up to that time they had been quartered in barracks, while afterward they were allowed to live where they pleased, often in little shacks scattered along the line. It was thought that these new conditions operated by lessening the chance of contact infection.

SMALL-POX.

Small-pox had at times been more or less epidemic among the French employees, and was prevailing on the Isthmus at the time of American occupation. Vaccination was made compulsory, and the disease soon disappeared. There have been no cases among American employees. There were three deaths from small-pox in the city of Colon in 1906-1907; since then two cases have been reported, but none have developed on the Isthmus.

III. PERIOD OF OPERATION OF THE PANAMA CANAL.

Various writers have stated that when the Canal was finished the organization of the Sanitary Department, which had been so efficient during the construction period, was to be allowed to lapse, and that the Isthmus would be allowed to grow up in jungle and go back to the old conditions existing during the French time. Nothing is further from the truth. As a matter of fact, there will be more cleared area when the work is finished than there has ever been; the troops will occupy all the abandoned sites except those which have been covered by the deep water of the Gatun and Miraflores lakes, and in addition several areas which have never been occupied before.

The clearings which it is necessary to maintain, to expose the field of fire about the fortifications, have also removed extensive mosquito shelters and helped to dry the ground.

The Sanitary Department, together with the rest of the organization on the Isthmus, was re-organized April 1, 1914, for permanent work during the period of operation, its designation being changed to Health Department. As now organized, it embraces three sections: (1) The Division of Hospitals and Charities; (2) The Division of Sanitation, and (3) The Division of Quarantine.

The Division of Hospitals and Charities.

This includes the large general hospital at Ancon, which is for employees, members of the Army and Navy and of the Merchant Marine, Canal Zone charity cases, and such private patients as may apply. It is so equipped as to take care of any sick that may be left by ships in transit, and give them the most modern and up to date treatment.

At Colon there will be a small emergency hospital, which will take care of those sick and injured employees whose condition forbids their transportation across the Isthmus to Ancon Hospital, and also to take care of such citizens of the Republic of Panama as reside in Colon and vicinity, and who do not wish to come to Ancon Hospital.

Santo Tomas Hospital, in the city of Panama, is a Panamanian institution, but under the direction of the Chief Health Officer. The Panama Canal supplies the Superintendent, two physicians, and three nurses. In order that we may control its policy and administration, the Junta of the hospital has, as its President, the Chief Health Officer, and, as one of its members, the Superintendent of the Hospital, who is also an American official.

The Palo Seco Leper Asylum, which is located about five miles (8 kilometers) down the Bay of Panama, is an American institution, which cares for all lepers, including those of the Republic of Panama, the latter being paid for by the Panama Government at a fixed rate.

The insane of the Republic of Panama are cared for in the same way, in the insane department of Ancon Hospital. Those insane males, whose condition permits, form a colony at the Corozal farm, where they do much valuable work with great benefit to themselves. It is intended, as soon as practicable, to remove the entire department to the farm, where the "open door" method of handling the insane will be put in practice.

The farm, which is for the purpose of taking care of permanently disabled employees of the Panama Railroad and Panama Canal, is located at Corozal. Here this class of patients are permanently cared for and given such employment as their condition permits, and remunerated therefor.

Besides the hospitals there will be three or more perman-

ent dispensaries where emergency treatment and home visits will be made by the District Physician in charge. These will be located at Gatun, Pedro Miguel, Balboa, and possibly elsewhere.

Division of Sanitation.

This division includes the Health Offices of Panama and Colon, and the Canal Zone Sanitary Division. The Health Officers of Panama and Colon have charge of street cleaning and garbage removal in those cities, besides the ordinary duties of health officers.

The Division of Zone Sanitation will include the districts of Gatun, Pedro Miguel, Ancon, and Balboa. The only difference in the character of work done in these districts in the future as compared with that done in the past will be that all future work will be of a permanent nature, so that the cost of maintenance will probably be greatly reduced. There will, however, be no let-up in the thoroughness of the measures undertaken to prevent disease.

Division of Quarantine.

The duties and responsibilities of this division are expected to increase greatly with the increase of commerce through the Canal. The passage of ships through "in quarantine" will introduce a new feature, which has been carefully provided for.

IV. COST OF SANITATION.

It is important that the cost of the Sanitary work done on the Isthmus, and by which it has been made healthful, should be accurately determined, because if it can be shown that such cost was reasonable, and not beyond the ability of the ordinary tropical government, then other countries in the tropical zone can be made equally healthful, and their responsible officials will be encouraged to do so.

At the beginning it is necessary that a clear distinction should be made between the "cost of the Sanitary Department", and the "cost of sanitation"—two quite different items.

The scope of the work done by the Sanitary Department on the Isthmus includes many things not included under sanitation or preventive medicine elsewhere.

More than half the cost for the Sanitary Department was due to the system of hospitals which take care of the sick; other large items were: street cleaning and garbage removal; the quarantine service; pay of all physicians on the Isthmus; pay of the chaplains; the water and sewer systems of Panama and Colon; the pay of embalmers, etc.

Col. Gorgas, the Chief Sanitary Officer, has stated that the cost of "sanitation proper" was about one cent per capita per day, for the total population, and that when the Canal is finished the cost of sanitation proper will have been about $4,000,000, or about $400,000 per annum—one percent of the total cost of the Canal works. (7)

Mr. Bishop, Secretary of the Isthmian Canal Commission, has shown in his book that the total cost of the "Sanitary Department" when the Canal shall have been completed, will be about $20,000,000, including two and one-half million dollars spent for sewers and water works, and in addition the usual overhead charges; he estimates that the cost of "sanitation proper" will have been about $6,000,000, or about fifty percent greater than the amount estimated by Col. Gorgas, the Chief Sanitary Officer. (8)

The difference in these two estimates appears to be due to a difference of opinion as to what items should be included in "sanitation proper".

V. RESULTS.

The results obtained by these expenditures have already been shown in other pages. Tropical diseases and some of the other specific diseases have been practically eliminated, and our sickness and mortality rates compare favorably with those of healthful communities in the temperate zone.

Col. Gorgas believes that there is nothing inherently unhealthful in life in the tropics, and that the results obtained in Panama demonstrate that the Caucasian race, under proper conditions, can live and work in the tropics as well as in the temperate zone, and that they can obtain greater results with the same expenditure of labor. He foresees the growth of important communities in the tropical areas.

While I believe that what has been done in Panama can

be done anywhere else in the tropics, with the same expert supervision and an equal expenditure of money, I cannot agree with Col. Gorgas that the tropics will ever be a suitable, permanent dwelling place for the Caucasian race.

In my opinion, even after diseases considered more or less peculiar to these regions have been eliminated, the effect of constant heat and moisture, without change of season, is to induce a condition of nervous and physical depression which cannot be overlooked. Some few people apparently escape these injurious effects for long periods of time, but the great majority do not.

What will be the result in the second or third generation, upon Caucasians living as we are doing in Panama, it is impossible to foretell, as like conditions have never been obtained before. The experiences in India and in other tropical countries, of what seem to be the effects of heat and moisture, *per se* are, however, against Col. Gorgas' conclusion.

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Paper No. 5

PRELIMINARY MUNICIPAL ENGINEERING AT PANAMA.

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In some popular writings it has been claimed, and it is a very general impression, that the municipal engineering work done on the Isthmus was inaugurated at the suggestion and carried out under the direction of the head of the sanitary department. This is not the fact. Reference to the original estimate of the Isthmian Canal Commission in its report of 1901 will show that there is therein included an allowance of 20 percent in the cost of the Canal for "engineering, police, sanitation and general contingencies". For the purpose of comparing the Nicaragua and Panama routes the same percentage to cover these items was used on both estimates. It was considered that while there were apparently fewer engineering uncertainties at Panama, due to the large amount of work already performed by the French Company and that in consequence various exigencies which increase cost would be greater in Nicaragua with its increased length of route and untried features—all this would be offset by the more dangerous health risks at Panama on account of the larger population and the almost continual presence of yellow fever. It was therefore rightly assumed that a larger relative amount would have to be spent at Panama in order to preserve health conditions.

The Act of Congress authorizing the Isthmian Canal was approved June 28, 1902, empowering the President to make all necessary arrangements with the Republics of Colombia, Nicaragua and Costa Rica for the acquiring of territory for canal

construction for whichever route should be adopted. Article 7 of the treaty finally ratified between the Republic of Panama and the United States under date of February 23, 1904, contained the following provision: "The Republic of Panama grants to the United States, within the limits of Panama and Colon * * * the right to acquire by purchase or by the exercise of right of eminent domain, any lands, buildings, water rights or other properties necessary and convenient for the construction, maintenance, operation and protection of the canal, and of any works of sanitation such as the collection and disposition of sewage and the distribution of water in the said cities of Panama and Colon, which, in the discretion of the United States may be necessary and convenient for the construction, maintenance, operation, sanitation and protection of the said canal and railroad. All such works of sanitation, collection and disposition of sewage and distribution of water in the cities of Panama and Colon shall be made at the expense of the United States, and the Government of the United States, its agents or nominees shall be authorized to impose and collect water rates and sewerage rates which shall be sufficient to provide for the payment of interest and the amortization of the principal of the cost of said works within a period of fifty years and upon the expiration of said term of fifty years the system of sewers and water works shall revert to and become the properties of the cities of Panama and Colon, respectively, and the use of the water shall be free to the inhabitants of Panama and Colon, except to the extent that water rates may be necessary for the operation and maintenance of said system of sewers and water".

Immediately upon the ratification of this treaty the President appointed the second Isthmian Canal Commission, which made a preliminary investigation of conditions on the Isthmus in April, 1904, previous to the final transfer of the properties of the French canal company to the United States. As a result of these preliminary studies and conforming to the implied intentions of the treaty, it was determined by the Commission to undertake complete municipal improvements in the cities of Colon and Panama, as well as in the smaller towns of the Canal Zone as works of necessity for the preservation of proper

sanitary conditions; while at the same time in order to protect the health of the employes of the Commission and of the inhabitants of the Canal Zone by the elimination of the epidemic diseases constantly prevalent on the Isthmus and by the establishment and maintenance of proper sanitary conditions from a health standpoint, the Department of Health was organized under a chief sanitary officer whose duty included the maintenance of a proper quarantine to prevent the entrance to the Canal Zone of disease, the establishment and operation of hospitals for the treatment of the sick, the necessary work of cleaning to eliminate disease-spreading conditions in the existing settlements, as well as the isolation and eventual eradication of such epidemic conditions as then existed.

It was recognized that this sanitary work would be facilitated and in many cases rendered possible only by the existence of a proper water supply and system of sewers, as well as the establishment of roads for proper means of communication between the settlements, and practically the first work of the first chief engineer, Mr. John F. Wallace, when he arrived on the Isthmus in June, 1904, was to make an investigation for a feasible water supply for the city of Panama. A party of engineers organized for carrying on this work and appointed by the Engineering Committee of the Commission reported for duty on the Isthmus shortly after the arrival of Mr. Wallace and entered upon the active work of planning and constructing the necessary municipal improvements. At this time the principal population on the Canal Zone was in the city of Panama, containing nearly 20,000 inhabitants. Colon at the Caribbean end of the Canal had a population of possibly half that number; while along the Panama Railroad and the canal location as started by the French company were many small towns containing a few hundred inhabitants each, many of them occupying buildings abandoned by the French contractors. Sanitary conditions in all these settlements were bad judged by modern standards.

The most vital necessity of any community, a water supply, was in all cases inadequately provided. Wells or running streams adjacent to settlements were the principal sources of water supply, supplemented during the season of dry weather,

which there lasts from the end of December to the latter part of March, by water collected from the roofs of buildings and stored in cisterns. Some attempt had been made to remedy this condition in the principal French camps where a few pumping plants were used for filling tanks of limited size from which the water was distributed by small antiquated pipe systems to a few important dwellings. In any extensive period of drought the wells and cisterns of Panama were inadequate and were supplemented by water collected from wells outside the city and peddled from small carts through the streets.

The situation of Colon was even more unsatisfactory and water had to be brought in during the dry season in tank cars, for the use of the employes of the Panama Railroad, who formed the principal white population. For Panama City a system of water supply from the Juan Diaz River, distant about ten miles to the eastward, had been contemplated by the local authorities. This would have furnished a constant supply even in dry weather, but the scheme was never carried out on account of the prohibitive expense.

Due to the discoveries made subsequent to the Spanish War in the city of Havana as to the true source of the propagation of tropical fevers, the eradication of mosquitoes around settlements was necessary. It was seen immediately by the medical men that the task of eliminating them from Panama City would be hopeless as long as rain water leaders, cisterns, wells and other possible water-containers were necessary features, and the installation of a system of water supply and sewerage, which had been originally contemplated for its convenience to a large population, was recognized as the only possible means to render the conquering of malaria and yellow fever feasible.

Panama City had been the headquarters of the French company. It was the capital of the new republic and in its vicinity was a large hospital with many buildings still in a good state of preservation which had been constructed under French management. As the only habitable headquarters for the commencement of work, it was considered of the utmost importance to start sanitary improvements here. The principal energies of the Commission the first year of the improvement

work were directed toward the sanitation of Panama; although, at the same time, investigations were started for sources of water supply for Colon and smaller towns, and minor improvements to their water supply were made. A description, however, of the work in Panama will outline the most important accomplishments in this line and will give a general idea of what was done during the first three years, which were largely devoted to organization, the assembling of plant, studying of final plans and establishing fit living conditions for the large organization which was, at the end of that time, prepared to undertake, on a large and definite scale, the carrying to completion of the great task of constructing the Canal.

The principal construction work accomplished by the French company had been the excavation of Culebra, and it was in the vicinity of this point that its main settlements and working plant had been assembled. Part of this method of procedure had involved the commencement of under-water dredging, at the earliest possible moment after dry excavation had been inaugurated, by the construction of small basins artificially supplied with water, in which ladder dredges could be floated, designed eventually to dig down to sea-level. To secure water supply for this and other purposes in the vicinity of Culebra, a dam had been built on a small stream known locally as the Rio Grande, near where it was crossed by the Panama Railroad, and this water was used for machinery supply as well as for household purposes in neighboring encampments. This early presented itself as a very obvious solution for a source of water supply for the City of Panama, and attracted Mr. Wallace's favorable notice, rather than the alternative idea, urged by citizens of Panama with private interests to serve, of the use of the Juan Diaz River; because, while the latter was situated at a distance of ten miles away from the Canal line, the Rio Grande supply was not only within the Canal Zone but immediately adjacent to the line of the Canal near its highest point, and could be used to furnish water, not only for Panama City proper, but for all towns on the southern slope of the divide, or nearly one-third the Canal route.

The first work, therefore, of the Municipal Engineering Division after its organization under two residencies, one

charged with the Pacific and the other with the Caribbean end of the work, was to make a rapid survey and estimate for the immediate supplying of water to the city of Panama from the Rio Grande reservoir, a bacteriological and chemical examination by the Sanitary Department having shown it to be an entirely proper source for potable water. The first party, the nucleus of the organization subsequently developed into the Municipal Engineering Division of the Isthmian Canal Commission, arrived on the Isthmus July 19, 1904. On August 6 a report was in the hands of the Chief Engineer of the Commission, recommending a water supply system consisting of, first, a storage reservoir on the Rio Grande; second, a 16-in. supply line extending from this reservoir to; third, a distributing reservoir at Ancon; and, fourth, a distributing system of pipes throughout the city of Panama; the entire supply to be by gravity at an estimated cost of $440,000.

Simultaneously with the making of these surveys, but requiring more time before their completion, detailed surveys and studies of the city of Panama were made for a sewerage system, and on August 26 a report with estimate and recommendations was ready for action. The question of disposal was comparatively simple. The extreme tidal range in the Bay of Panama varies from 14 to 20 feet. The city as it was rebuilt in 1673, after its destruction by the Buccaneers, occupies a site on a peninsula five miles to the westward of the original location, laid out on what was then a massive scale surrounded by a masonry wall, with streets on a generally rectangular system, but usually narrow, the width varying from 20 to 60 feet. The blocks were solidly built up, after the usual Spanish system, having masonry buildings two or three stories in height with interior courts, narrow sidewalks—usually not over three feet in width—adjacent to the buildings, which are overhung by balconies and, between the curbs, the streets were as usual paved with small cobbles obtained from neighboring streams. Like all Spanish-American cities, the sidewalk widths and heights were largely a matter of individual choice, so that continuous travel along the sidewalk was frequently impossible or, at best, required frequent ascent and descent. The stone pavements, while rough, were laid to a generally even

surface and served fairly well for more than 200 years to carry all the traffic that came on them, which consisted largely of two-wheeled carts and light carriages. Such sewers as existed were rectangular stone drains discharging at the foot of each street through the wall.

Fig. 1. An Old Panama Street After Water-Main Had Been Laid on Left. Most published views showing Panama streets ''before paving'' were taken after settlement of sewer backfill in the rainy season.

Outside of the city wall, to which the water came at high tide, the beach, rocky in some places, sandy in others, extended for a distance varying from a few hundred feet to half a mile to extreme low water mark. It was seen that, while no nuisance would be occasioned to the city by the discharge of sewage into the bay with its strong tidal currents, it would be necessary

to place the outlets at low water mark to avoid any pollution of the beaches, and it therefore became requisite to find suitable points for outfalls, the location being governed, both by the drainage area to be served, and the possibilites of constructing an outfall sewer in a permanent manner, across the strip of territory exposed at low water. Inspection of the map, and of physical conditions at low water mark, showed three points where high

Fig. 2. Western Outfall at Half Tide.

and low water marks were reasonably near together, while the shape of the city rendered its division into three drainage areas most suitable. The first of these was the main body of the peninsula proper, or the easterly portion of the city, inside the old walls, which could conveniently be drained into an outfall which would lead to low water mark, at a distance of only five or six hundred feet east of the main fortification lying along the easterly sea wall; while the other two districts comprised, respectively, those portions of the city which had grown up outside the old walled town to the east, and to the southwest, the former draining into the bay at a point along the beach where

it was reasonably steep, about half a mile northeast from the Panama Railroad terminus, and the other having a natural approach to low water near a little island close to the Zone line, and immediately south of Ancon Hill. These points being decided upon, and a line of intercepting sewers reaching to each outfall being laid out at the maximum available grade, the remaining task consisted of planning a series of sewers in

Fig. 3. A Sanitary Ditch Several Times Too Large. It was built without engineering supervision and was too high to drain the adjacent ground. Finally covered with reinforced concrete by the Municipal Engineering Division and field graded to a higher level. This drainage work was started by inexpert assistants of the hospital force.

the three districts named, which would reach these intercepters with a minimum size and quantity of pipe.

With the grades prevalent in the city, sewers designed simply to carry off the house drainage would not exceed 8 to 12 inches in diameter, assuming a discharge of 60 gallons per head per day, with one-half the total entering the sewers in a period of seven hours. There were, in the principal streets, old stone drains of rectangular cross-section, discharging directly

upon the beach, and connected with a few of the houses in which some attempt had been made to install more or less primitive plumbing. They were all in an unsanitary condition, and it was decided that they should not form any part of the new system.

The question had to be considered whether there should be any provision made for the discharge of storm water, which at the time was carried off entirely upon the surface of the streets. Like all tropical places Panama is subject to torrential rainfall at times, also to long periods of drought. It was not desirable to construct sewers of a size adequate to take off the maximum rainfall, which has been known to amount to as much as an inch in ten minutes, necessitating excessively large sewers, which would be practically dry for a large portion of the time. On the other hand, due to the desire to eliminate all standing water to the greatest possible extent, it had been decided to pave the streets subsequent to the completion of the laying of the water and sewer mains, and to cement to the greatest extent all walks and yards, rendering it necessary that the streets take care of practically all rainfall without extensive absorption.

After considerable discussion a compromise policy was adopted. It was decided to construct the sewers in the central portion of the city, comprising mainly those in the first drainage district, on a combined plan having a capacity for an estimated runoff over the entire area of 2 inches per hour, with the exception of those streets within one block of the sea wall where all water would be allowed to run off on the surface. The buildings had no cellars to be flooded, and as all plumbing was necessarily at the street level or above, occasional backing up of storm water in the house connections, due to a greater runoff than the sewers could immediately discharge, would not cause any serious inconvenience. In view of the fact that a combined system was very much less expensive than a separate system and that the narrow streets made it inexpedient to lay duplicate lines of pipe, this plan was thought to be more desirable from all points of view, and subsequent experience justified it.

No provision was made in the intercepting sewers for carrying storm water to the outlets, and storm overflows were

planned and placed at the junction of the main intercepters with the outfalls, so that all excess drainage was carried directly through short lines to the sea wall, and discharged on to the beach. It was considered that the small volume of house drainage, diluted in the total amount of rainfall, and discharged under these temporary storm conditions, would be entirely inoffensive.

For those portions of the second and third districts distant from the water front, provision was also made for a certain amount of storm water, but only one-half as much was taken care of in these regions, as that portion of the city outside the old wall was very much less solidly built up, and the streets were somewhat wider and less congested. In all outlying portions of the city the separate plan was absolutely adopted and storm water sewers designed where necessary to take care of existing water courses. The estimated cost of sewerage system was $257,000.

The plans as adopted and built included the following principal items:

Water Works.

Dam and Storage Reservoir at Rio Grande. Max. Storage Capacity, 400,000,000 gal.

Supply Line Rio Grande to Ancon.

Galvanized Wrought Iron Pipe.

Size Inches	Total length Feet
20	4,000.0

Cast Iron Pipe.

16	46,000.0

Distributing Reservoir at Ancon. Capacity 1,000,000 gal.

Panama City Distributing System.

Cast Iron Pipe.

Size Inches	Total length Feet
4	8,804.1
6	40,552.3
8	6,058.3
10	1,444.5
12	1,443.5
16	1,235.0
20	2,060.0
Total length	61,597.6

House Connections	2,093
Meters	1,048
Water Cranes	7
Public Taps	35
Fire Hydrants	133

The design was based on an estimated maximum supply of 60 gals. per head per day for 30,000 population. Half this amount was adequate during the first three years.

Sewers.

Vitrified Sewer Pipe.

Size Inches	Total length Feet
6	2,200.0
8	36,004.0
12	16,263.8
15	5,490.9
16	127.0
18	5,165.2
24	580.6
Total length	65,831.5

Concrete Storm Sewers.

24	432.2
30	545.0
36	1,119.0
Total length	2,096.2
Manholes	261
Catch-Basins	227

Immediately upon the adoption by the Commission of the plans for water supply, requisition was prepared for the necessary materials and sent to the purchasing agent of the Commission at Washington, and the same procedure was followed on the adoption of the sewer plans a few weeks later. The specifications for the materials needed were necessarily hastily prepared, but followed the standard practice prevalent in the United States in a general way, and it was with surprise learned by those on the Isthmus somewhat later that serious delays in the procuring of the water pipe, which was the first article

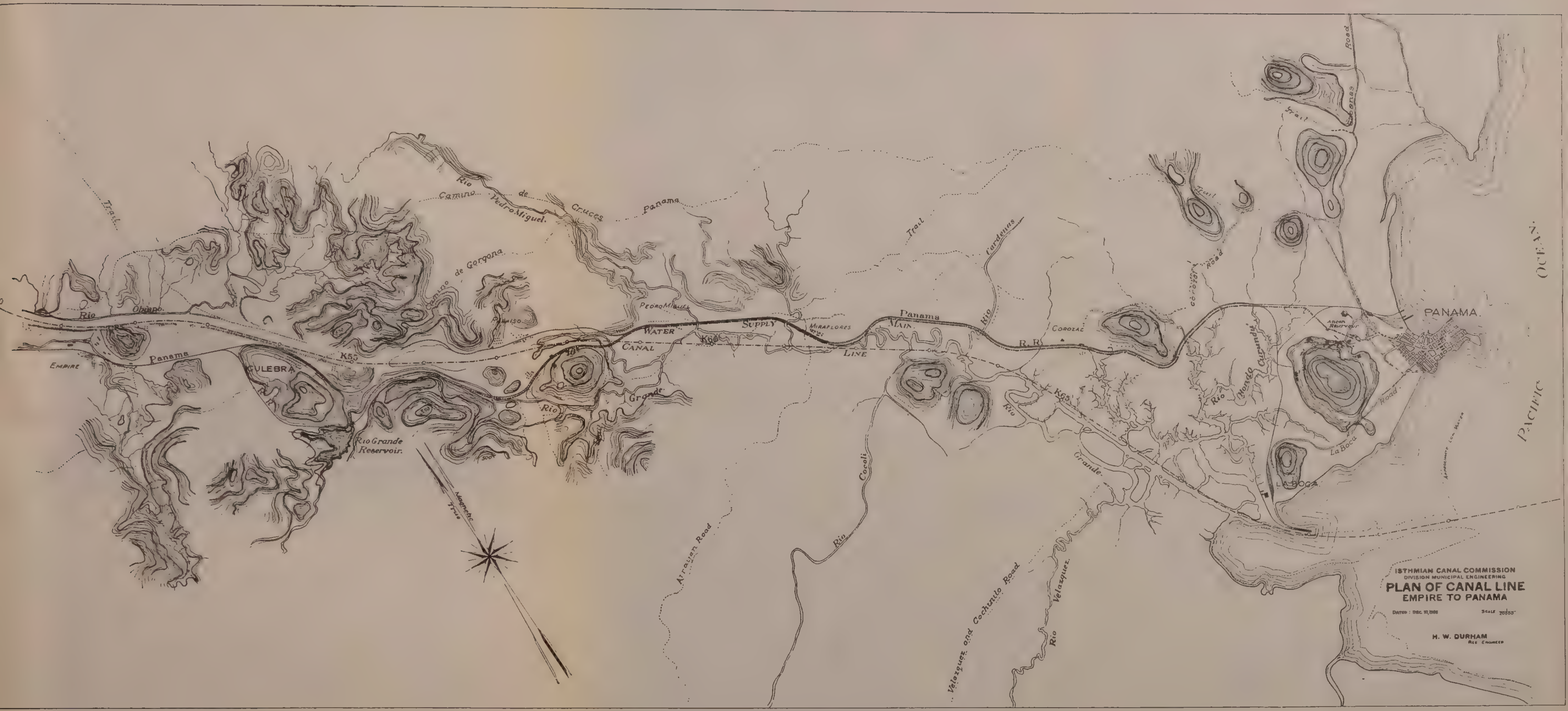

Plate II. Plan Showing Location of Reservoirs and Water Supply Line.

needed for the quick settlement of the water famine problem for the ensuing year, were caused by academic debates on the part of certain authorities as to whether Pacific coast specifications were inferior to those of New England.

On August 15, 1904, the first construction work was started on the proposed municipal improvements for the city of Panama. A gang of laborers was set to work clearing the reservoir site, and the work of raising the dam under the railroad

Fig. 4. Rio Grande Dam. Low water, with temporary pumping installation to raise water into gate chamber because of blocked lower valve.

bridge commenced at the same time, followed shortly after, and as soon as word had been received that pipe was ordered and on the way, by the clearing and commencing of trenching for the main supply line from the dam to Panama. All preliminary construction was undertaken with such laborers as could be recruited from the local supply not engaged on actual canal work, and with such tools and materials as could be picked up from the old French stock, or from the small supplies sent from the United States. As the dam to be raised was immediately under the railroad bridge, it was easy to utilize the lat-

ter by attaching brackets at one side for the construction of a working platform and gravity mixer. Materials were unloaded from a railroad spur at one end of the bridge and stored immediately alongside, and from this conveyed by small Decauville cars on portable tracks (a large stock of which was to be found at all points along the old French canal line) to and across the bridge. A gravity concrete mixer of the Haines type was improvised from two Decauville car bodies placed so as to form

Fig. 5. 16-inch Cast Iron Pipe Supply Line. A Stream Crossing.

buckets, one above the other, with movable gates in the bottom, the entire apparatus having been made in the Panama Railroad shops from old French scrap material. In this way concrete was deposited by gravity to form the raised portion of the dam, including a large combined gate chamber and buttress on its downstream face, so built as to furnish additional stability.

The old dam was of the arch type and, as reconstructed,

theoretically unstable, if supported by gravity alone, but its wings rested on solid rock and the combined buttress and gate chamber provided additional strength. The only absolutely

Fig. 6. Supply Line. The 20-inch Galvanized Wrought Iron Section Made of Old French Pipe.

new materials required were sluice gates and valves, and even here use was in part made of some old French valves.

By the time conditions were in readiness for the com-

mencement of laying the main pipe line from the dam to Panama, no material had been received on the Isthmus, and, as it was inadvisable during the rainy season to leave trenches standing open for any considerable length of time, some means had to be taken to secure a substitute for the delayed material. There was found in the French storehouses and at other points on the line a large amount of galvanized riveted wrought-iron pipe of approximately 20 inches diameter, which had been supplied originally for use with hydraulic dredges, and part of which had been laid from the dam to the Culebra Cut for the purpose of temporary water supply. This pipe was relaid beginning at the dam for a distance of nearly 4000 feet. It was in 16-ft. sections with flanged ends composed of single riveted cylinders with in and out joints, the metal having a thickness of 1/8 of an inch. It was connected by bolting the flanges through rubber gaskets to insure tightness, and, as a precaution against damage after having been laid, was surrounded with approximately 6 inches of concrete.

It was necessary at various points to carry the pipe line across small valleys or over culverts and bridges on the railroad. These crossings were generally made by trussing the pipe with iron rods and supporting the trusses, either on the bridge abutments or intermediate trestle bents. In the case of the longest trestle where the Panama Railroad crossed the old canal line, it was supported on auxiliary bents alongside.

Shortly after commencing work on the dam and supply line, a small force was organized for the construction of the Ancon storage reservoir. This was a concrete basin with a capacity of 1,000,000 gal. divided in two parts by a center wall. The reservoir was situated at the summit of a small hill adjacent to the hospital grounds, selected principally because it had such an elevation that the reservoir, when constructed for about one-half its depth in excavation, would be at the proper elevation for the hydraulic gradient. This excavation was carried on during the subsequent season, but, on account of the great scarcity of water prevailing in Panama during the dry season of 1904-05, it was impossible to commence concrete work, and consequently it was left, after the completion of the timber forms, until after the introduction of water into Panama through

the main supply line, which was by-passed around the reservoir. The first pipe for the supply line was not received until February 1, 1905, final delivery May 24, and one month later the entire line had been laid, riveted and calked, permitting water to be introduced into the city of Panama by July 1, and turned on, with appropriate ceremonies in the public square, on July 4, 1905.

While the laying of the main supply line and raising of the Rio Grande dam were going on, the work in the city of

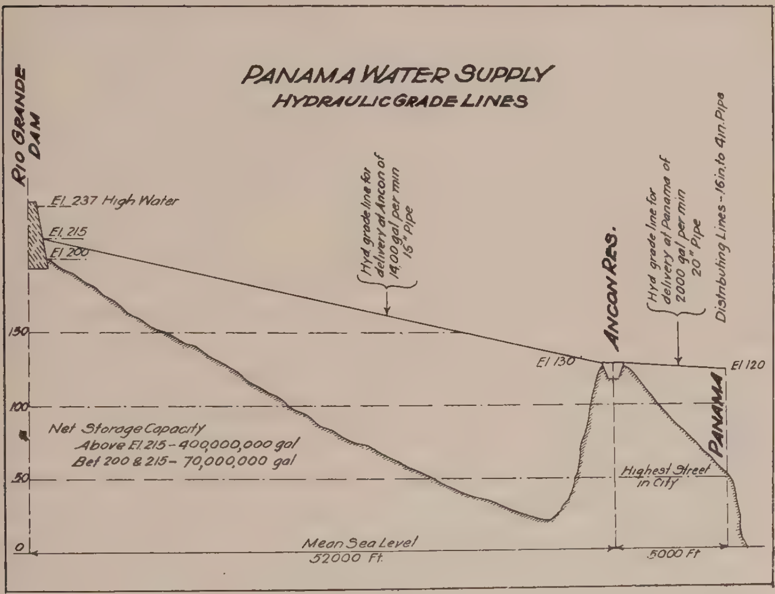

Fig. 7.

Panama was being inaugurated under a separate organization. As soon as the report on sewers had been approved, specifications for material were made and forwarded to the United States. As in the case of the water supply, however, it was found inadvisable to wait for the delivery of materials, and work was started on October 19, 1904, excavating for the main outfall sewer under the old Chiriqui Fortress. To construct this sewer required a tunnel 100 feet long under the parapet of the fort, and, as materials were again delayed in delivery after

the time of completion of this tunnel, an 18-inch concrete sewer was built here and carried 300 feet beyond the sea wall to low water.

The work as carried on during this first year was divided into three divisions, supervised by members of the original engineering party who had been first employed on preliminary survey. Necessary superintendents and foremen were first hired on the Isthmus, and later supplied from the Washington office. Their laboring gangs were, in the same way, first recruited into small units from the local labor markets, and later supplemented by the organized efforts of the Bureau of Labor of the Canal Commission. Laborers employed at the dam and along the Panama Railroad consisted mainly of Jamaica negroes. In the city of Panama it was more difficult to maintain men in steady employment, due to the fact that there was a constant drifting population through the city, and incessant recruiting was necessary.

Shortly after the commencement of sewer work came the enforced disbanding of the Panama Army, consisting of some hundred men, who, with their captain in command, were turned over to the Municipal Engineering Division to make themselves useful. The captain was constituted foreman and his men assigned to the gang under him, with the result that within a month no trace of the Panama Army remained in the city, with the exception of the captain, who subsequently resigned.

Following this a gang of laborers was secured from the interior of the country by sending an agent, who brought them in a schooner to Panama. The men when they arrived had no money with which to provide food and quarters, and the Paymaster's department absolutely refused to make any advances until wages had been earned. It was consequently necessary for the heads of the Municipal Engineering Division to finance the food and quarters of these men until the first pay day, depending upon individual reimbursements, which were not in all cases secured.

Eventually the department in charge of the securing of labor and providing quarters began to send small gangs from the various West India islands. Eager competition to secure these men developed between various divisions anxious to carry

on their work, and there came about a system of recruiting in each division, which sometimes resulted in the offering of inducements to laborers to leave one portion of the work and go to another, a practice which prevailed for many months before it was finally stopped by those at the head of the work. In one case when a shipment of laborers arrived at the Panama Railroad station they were met by agents of the Municipal Engineering Division and others from the Building Department, and so keen a competition developed to obtain the men that there ensued a street fight and the subsequent arrest and jailing over night of the principals, all parties being let off the next day with fines, those for the Municipal Engineering Division being the greater, as the Building Department's men showed the greater number of surface damages.

Conditions in the city during the first year of work were excessively bad. More or less yellow fever was constantly present in the city with malaria very prevalent, and the problem of obtaining quarters for men was much more difficult than along the canal line, where many old French buildings were available. After several months, when the sewer construction was thoroughly under way, and laborers obtainable in larger numbers, it became necessary to obtain from the Panama Government the use of part of the old Chiriqui barracks, which up to that time had been used for a prison exclusively, and to quarter our laborers therein. As it was still continued in use as a prison with the consequent military guard, there arose on various occasions trouble, which culminated in a riot and the injuring of several men by Panama police, some twenty laborers from the sewer gang being conducted to the Ancon hospital with bayonet wounds in the back. Trustworthy foremen were hard to acquire and harder to keep at work. More than one died of yellow fever, and others left on account of ill health or dissatisfaction with living conditions.

Simultaneously with the pipe laying in the streets, the Sanitary Department was carrying on a campaign of fumigation in an attempt to eliminate epidemic diseases. This required a large number of laborers at necessarily easy work, consisting mainly of fumigating and whitewashing buildings, and, as no distinction was made in the rates of pay allowed to different

classes of labor, it was increasingly difficult to hold men to work in the trenches for the same price that they could receive for standing on a ladder with a whitewash brush, or sitting on the curb waiting until the work of fumigation would permit their entering a building to clean it. It was intended and attempted to carry on simultaneously in any one street all the work of pipe laying required, but after the first attempt the plan was given up, as the narrowness of most of the streets prevented the piling adjacent to the trench of all excavated material required for the laying of both sewers and water mains, and it was found impossible to carry on the different steps of the two classes of work simultaneously. As far as was possible water mains were laid with a view to completing the central skeleton first and carrying the main supply line down the principal street and thence on radiating branches; while, on the other hand, the logical development of the sewers began with the outfalls and from them worked back towards the main street, which was on the crest of the central ridge of the city. The work on the streets for sewers and water mains was inaugurated at the close of the wet season about February 1, 1905.

As labor was cheap and largely unskilled, it was decided to make sewer manholes of concrete, and, on account of the firm nature of the material excavated, a large number of these were constructed by digging a circular hole of the exact size of the manhole in advance of trenching, thus avoiding the necessity for exterior forms. While awaiting the arrival of supplies and subsequently on various occasions when these were inadequate several concrete sewers were constructed.

Almost simultaneously with the commencement of the construction of water works and sewers, some small road construction had been carried on. It had been necessary, from the first, to do maintenance work on the roads built by the French canal company in and about Ancon Hospital and the headquarters of the Commission on territory outside the City of Panama and within the canal zone, and it was recognized that the authorities of the City of Panama had no organization for maintaining the surfaces of their streets after the original hard foundation should have been cut by trenching.

The first actual work of any consequence in highway main-

tenance came as the result of the imminent failure early in 1905 of the plate girder bridge carrying the main street of Panama over the Panama Railroad tracks adjacent to the main passenger station. As it was found that the railroad company had no adequate force for its repair, and that the Building Department was unable to undertake it, the matter was turned over by mutual consent to the Municipal Engineering Division to

Fig. 8. Caledonia Bridge. The old corroded plate girder structure carrying Central Avenue over the Panama R. R. Bullet holes from recent revolution show in sheet-iron parapet.

remedy. The plate girders had been so badly corroded by locomotive gases that the webs were almost entirely destroyed near the center panels, and many of the floor beams badly disintegrated. As an emergency measure it was decided to encase the entire structure, which was still capable of sustaining not only its own load but something more, in a concrete arch, and designs were accordingly worked out, the girders stripped and raised about two feet from their foundations, forms erected,

and a concrete arch bridge, having the two main girders encased in concrete panels, and the entire structure embedded in a three-centered concrete arch of low rise, was constructed at a total cost of about $3000. It was erected in a period of two months without interfering with railroad travel.

Subsequently, beginning with a relatively small amount, the entire work of road construction was turned over to the Municipal Engineering Division. The only work done at first

Fig. 9. Caledonia Bridge. Concreted and Face Forms Removed.

was repairs to roads around Ancon, and the resurfacing of the main road leading from Panama to La Boca. This was with material obtained from a small quarry on the west side of Ancon Hill, and, until a steam roller could be obtained, use was made of a horse-drawn roller constructed of a section of cast-iron pipe filled with cement. At the same time that this was being undertaken, the Panama Government was attempting to develop its territory in the district known as the Savanas, lying

along the old road which ran, in a generally easterly direction, from the city, near the site of old Panama, to the Juan Diaz River and beyond, the region in which many of the wealthy Panamanians had large estates and houses, which they occupied during the so-called summer season, the dry period extending from December to April. As the road to this district passed for several miles through canal zone territory, it was agreed by the Isthmian Canal Commission to improve the old highway with a modern macadam road. The old road was

Fig. 10. Caledonia Road. Start of Route to the Savanas.

largely in two sections, one-half paved with cobblestone, which portion was used in wet weather, and the rest merely a dirt trail which had a smoother surface in the dry season but was very dusty. In wet weather this latter portion became speedily impassable.

Shortly after this work was planned and commenced, plans were laid out for the paving of the city proper. This was during the rainy season of 1905, shortly after the turning on of water along the central street of the city, and the completion of the

first sewers. Any attempt to restore the old cobblestone surface over the backfilled trenches would have been useless, even had it not been determined that for sanitary reasons a smooth pavement easily kept clean and drained was most desirable. To furnish such surface, vitrified brick was selected as most suitable for the climate and local conditions. For the principal street of the city, which has a length of about one mile between the railroad station and the central plaza, and a width varying from about 40 to 80 feet, and which carries the heaviest traffic,

Fig. 11. Savanas Road Where a Cut Was Made. Two months previous this spot was impassable, due to mud.

5-inch concrete foundation was used, the brick surface being laid on a 1-inch sand cushion. For the other principal streets a 4-inch concrete foundation was thought to be adequate. On streets of minor importance it was planned to lay brick directly on a rolled macadam foundation, and ultimately, over a considerable number of them, the brick was omitted entirely and a 5-inch concrete roadway constructed with a smooth surface. It was originally planned to fill the joints of the bricks with a

bituminous material, and the original requisition was made up on this basis. It was later determined, after the receipt of supplies, that, due to climatic conditions, cement grout would be more satisfactory, and the other method was never tried out.

On account of beginning paving construction a year before the force engaged on sewers and water mains in the outlying portions of the city could be materially reduced, there was necessitated a considerable increase of force and the appointment of additional supervisors competent to handle paving work; while simultaneously the special division charged with macadam road construction had to be enlarged as the scope of this work extended to the reconstruction of all the outlying roads around Panama.

Upon commencing the street paving it was first necessary to have a storage yard, and, there being no sufficient room in the freight yards of the Panama Railroad, some adjacent ground was leased for a period of two years, spur tracks constructed from the railroad running to sheds for the storage of several thousand barrels of cement (which was received in shipload lots) and a trestle over bins for crushed stone and sand, as well as vacant ground on which to pile at least 3,000,000 brick. The broken stone it was planned to supply from a crusher plant at Pedro Miguel on the line of the Panama Railroad.

The organization under the Resident Engineer at this time consisted, in addition to the necessary office force and survey parties, of four principal divisions: one handling all the work of water works and sewer construction in the city; one in charge of similar work in the outlying towns as far as Culebra; a third constructing macadam roads; and a fourth, the last organized, but ultimately the largest, for paving the City of Panama. There were also necessary the transportation organization for handling material by cart to the various jobs, and a storekeeper with assistants in charge of the issuance of materials. The whole comprised about 1500 men.

As had been the case previously with supplies for water mains and sewers, a long period elapsed after the drawing of requisitions before the materials called for were received. There was great urgency during the latter months of 1905 to

commence the work of paving. Requisitions had been drawn under the direction of the first Chief Engineer; the supplying of them developed upon the second appointed; and a complete reorganization of the commission had also taken place. These changes necessarily involved delays in the receipt of material, but also brought upon the Municipal Engineering Division much urgency for expediting the work. The grading and placing of foundation concrete on the main street was therefore started, before any brick had arrived, with gangs recruited from among the men then available. One of the assistant engineers was put in charge of paving construction as superintendent. Two general foremen were found who had at some time seen or read of the construction of brick pavements, and the work on the main street was divided into two sections. There was not a laborer available who had ever had anything to do with any class of paving construction, and very few who had ever worked on any construction other than simple excavation. The engineer-superintendent was one of several men in the organization who had sufficient executive ability to handle his force, and soon developed the elements of what was desired.

It had been planned to use mechanical mixers for the foundation concrete, and requisitions had been made with this in view, but, unfortunately, when these arrived they were found to be about two sizes too large for Panama streets, and they were therefore left in the storage yard for a year or two, while the work on the street was carried on very satisfactorily, with less complication and at no greater expense under the existing conditions, by hand mixing. There was requisitioned at the same time as the concrete mixers and other supplies for paving, a small 5-ton tandem roller, which it was proposed to use in the city, and two large rollers of about 12 tons each, for use on the macadam roads. The former was received in time to place in service for consolidating the sub-grade in advance of paving, as well as for rolling the brick surface, and, after some delay, the first shipment of brick, containing enough to pave the first quarter mile of the main street, arrived at Colon. From the first the handling of the brick was done in a very crude manner. They had been shipped roughly dumped in the hold of

the steamers, were unloaded by grab buckets to side dump cars, on which they were transported to Panama and dumped in the storage yard, having at no time any care used in the handling. The result was a very high percentage of broken brick, which was later utilized by mixing with broken stone for foundation concrete. The paving of the main street was commenced in November, in the midst of extremely wet weather, and carried on continuously except when delayed by lack of material, and finished in March, thus obviating the greatest source of complaint and relieving the traffic situation, so that the paving of the remainder of the city could be carried on with somewhat less inconvenience to the general public.

It was found, soon after starting the work, that the supply of crushed stone from the Panama Railroad crusher was irregular and inadequate, and a search in the vicinity of some of the old French warehouses resulted in the finding of a number of small portable jaw crushers that had been overgrown with trees and jungle for the previous twenty years. These were hauled out and one was set up in a public square near the center of the city, for the purpose of crushing the old cobblestone pavement as it was removed from the streets, while two others were employed on the work of constructing macadam road to the Savanas, in place of two American crushers, which had been bought on requisition and which speedily broke down under the hard service given them.

The paving of the city was continued throughout 1906, being finished early in the following year, and amounted to a total of 65,000 square yards of brick pavement with a total length of 5½ miles, about two-thirds of this on concrete foundation and the remainder on macadam. There was also laid about 19,000 square yards of concrete pavement, having a total length of two miles. Concrete curbs were built on all streets. On account of the uniform temperature, no difficulty was experienced in constructing the latter in place to any length desired. No provisions of any sort were made for expansion, either in the concrete streets or curbs. There were few cases of cracks occurring. The paved portions of the city comprised all the old town inside the former line of the walls, and the central portion outside adjacent to the two main thoroughfares,

one leading to the railroad station and beyond to the Savanas, and the other forming the road to La Boca. The majority of streets adjacent to or outside of these principal arteries were surfaced with macadam with concrete gutters and curb.

In order to facilitate traffic in the congested portion of the city, a few grade changes were made, an incline being built from the higher portion of the city to the low level around the market, and another down to the beach, where the market boats

Fig. 12. A Narrow Street Paved after Making Grade Reduction. Sidewalks Subsequently Cut Down to Meet New Curb Level.

were accustomed to congregate; while, in the paving of all the streets, curbs were set to uniform grades and sidewalks subsequently brought to their level, thus abolishing the old custom of each owner having the walk in front of his house at whatever level best suited him, with the consequent impossibility of continuous foot traffic along the walks.

No serious accidents occurred at any time during the city construction, either in the trenching or subsequent paving. At the height of the first rainy season, while constructing a sewer

trench adjacent to the building then occupied as a residence of the chief engineer, caving developed, and it was necessary to keep a gang at work continuously for two days in order to protect the sides, shore the adjacent buildings and prevent damage. Later, in the construction of one of the storm overflows, which was built by tunneling near the ice plant, a second bad case of settlement happened, due to the buildings in the vicinity having been constructed on ground previously made

Fig. 13. Crowded Conditions on a Narrow Street. Deep Trenching on Avenue A* for the 24-inch Sewer.

by filling with garbage, and one wall of a house fell down. This was restored by the same construction gang building the sewer, and concrete instead of the previous rubble was used, resulting in a letter of thanks directed by the owner to the Governor of the Canal Zone for the generous treatment he had received. At one other point where a grade reduction was

* Engineer party's street designations, chosen for use in field notes, were officially adopted by the City.

made, it became necessary to do some hasty concrete retaining wall construction, to prevent the possible subsidence of a building which proved to have been built directly on the surface of the clay soil without any attempt at foundation.

All forms of street work were carried on under considerable urgency and pressure at all times, and at the best, especially because of the very narrow streets, there was considerable annoyance to property-owners, perhaps to none greater than to those in the street renamed Avenue A, where the main outfall sewer of the central portion of the city was laid at such a considerable depth that the excavated material could barely be stored on both sides of the trench, and only by putting stopboards across the doors of all the houses and piling up the material half way to the second story, requiring occupants to climb in and out over this barricade.

At a time when the paving construction work was at its maximum pressure and before the entire completion of the water works, but fortunately after the distributing reservoir and principal street lines were in service, occurred two serious fires. The first, probably caused by the operations of a fumigating gang, burned over several blocks in the western part of the city occupied by the poorer and most inflammable class of houses, but, as it happened at mid-day, the forces of the construction gangs were fortunately available for prompt assistance to the zealous but inadequate native fire department.

The second originated after midnight in a large lodging-house near the center of the city, and for several hours before daylight presented a very serious task to prevent its spreading over the entire town. As it was, the buildings over more than two blocks in the heart of the town were completely destroyed, but in both cases a demonstration was given of the efficacy of the water supply, without which the fires might have consumed the entire city. The hydrants and ample water supply were of course an entire novelty to the old fashioned fire department, whose members were always punctilious about putting on their uniforms before proceeding to a fire. They selected by preference those hydrants at a safe distance from the flames, then, after coupling their hose and turning on the water, proceeded to stretch lines ranging from 250 to 500 feet crossing each

other and sometimes running past unused hydrants. The ultimate extinguishing of the conflagration was usually done in spite of the department, by a large accession of volunteers from the Municipal Engineering Division forces.

While the city construction was under way, with all the difficulties due to working in narrow streets, the lack of water in the first dry season and the too great abundance of it in the subsequent rainy weather, with public dissatisfaction because conditions were not immediately made several hundred per cent better than they had ever existed before, and, with confusion due to frequent changes of overhead organization; the road construction division working outside the city was carrying forward, first La Boca and, later, the Savanas Road, with an organization which required even greater attention than that of the city, as, in addition to the problem of construction proper, was that of proper camps and commissary facilities as the distance from the city increased up to a maximum of six miles.

The equipment included teams, wagons, scrapers, plows, road rollers and two portable crushing plants set up at points adjacent to the road work where suitable rock could be obtained. Reference has already been made to a requisition for two road rollers for this work, which were needed to take the place of the horse roller first employed. The history of this requisition, while by no means typical of the history of all supplies purchased at that time, is an illustration of some of the difficulties experienced on the Isthmus, not confined to the period under control of the French company. From the time the requisition was forwarded until the rollers were received, several months passed, and, in the interval, the work on the Savanas road was inaugurated by using an old English Aveling and Porter roller belonging to the Panama Government, which was borrowed at times when it could be spared from the attempt which the native government was making to modernize its own road system beyond the Canal Zone. After a long wait two rollers were delivered at Panama and set up ready for work. They presented a handsome appearance with fresh gold lettering and green paint, and bore names professing that they had been manufactured by the Acme Road Machinery Company. After some difficulty in getting men expert to run them—as most of the ma-

chinists available were locomotive engineers of the Panama Railroad who had been discharged for drunkenness—they were started in operation, but speedily developed an alarming capacity for breaking down, which was at first attributed to the erratic conduct of the green rollermen. Within a few days, however, the large gear wheel on one roller broke in two, displaying a section of rust on the interior face of the break, which had been covered with putty and paint. Shortly after, the link block on the other cracked and, when removed, showed, under its coating of metal paint, an unmistakable hard wood surface. As the new paint began to wear off the covers, other names developed beneath it, which led to a belief that both machines were reconstructed traction engines, which had been formerly destined for Frankfort, N. Y., and Racine, Wis., but which for some reason had not been sold to those municipalities. Extensive repairs on both machines, as other flaws developed, ultimately put them in fair condition. It is probable that the total value of the shop work and subsidiary repairs given them on the Isthmus, within the first year of their service, equalled the original purchase price.

Reference has been made to such incidents as these, to show the difficulties under which the pioneer parties worked, during the first three years of preliminary preparation for the organization which has carried on the canal to completion.

By the middle of 1907, water works, sewers and paving had been completed in the City of Panama. Practically all houses had by ordinance been connected with the water mains and sewers. The Sanitary Department, as fast as this was done, required the filling up of wells, cisterns and the removal of all water containers. The main roads outside the city were finished, subsidiary water systems, taken from the main supply line, served all camps and towns from Culebra to Panama, and necessary roads had been finished in these settlements, new water connections provided for the Panama Railroad and the wharfs at La Boca, and a filtration plant installed for the clarification and purification of the water supplied from Ancon reservoir.

The hospital and quarters on Ancon Hill, which were too high for the city gravity supply, were served by a high level subsidiary reservoir filled by a pumping plant which also supplied steam to the hospital and hotel. Similar installations served

the other Canal Zone towns, while a pumping plant supplied Colon with water from a nearby reservoir too low for a gravity supply, and, on account of its flat and low situation, the entire town was raised several feet by hydraulic dredging, a sewer system constructed, with a discharge by pumping from a sump, and the street mainly surfaced with macadam.

In the city of Panama during the three years of preliminary construction there was expended for municipal improvements of all classes over $1,000,000; including Colon and the Canal Zone towns outside the jurisdiction of the Panama residency, the total work of the Municipal Engineering Division amounted to over $2,000,000. A comparison of the unit costs of work during this period with those in other places, or subsequently at Panama, is of little value inasmuch as the conditions existing frequently necessitated the attaining of prompt results without giving opportunity to pay much attention to economy. It was of course endeavored at all times to operate the organization as efficiently as possible, but frequently speed demanded the paying of extremely high prices for materials or the working of laborers in what would have been extravagantly large gangs under ordinary conditions. In addition to this is the fact that records as kept under the direction of the Canal Commission during the preliminary period are extremely poor. No general system of cost keeping had been adopted, and in general the official documents show merely total cost, with no explanation as to units, or reasons for special payments. An example of the impossibility of judging cost from the records is the case of the Savanas road. The books show an extremely high cost, and there is nothing in them to indicate that, as was the case, a large part of the plant and expenses entirely outside the control of the Municipal Engineering Division, were figured into the cost of this road.

The following are a few of the principal items of cost: There was expended on Panama pavements at the close of 1906, when the work was completed on the majority of streets, about $300,000. The total expenditures on the water works and sewers for the city to the same date amounted to over $600,000. Outside of the city, on the Savanas road and other roads of less importance, as well as subsidiary lines for water supply and sewerage in adjacent towns, there had been spent an additional amount in

excess of $100,000. The reconstruction of Caledonia Bridge, the concrete highway arch bridge over the Panama Railroad, was done for $3000. The total cost of the Savanas road, including three concrete arch bridges, regrading to the extent of 12,000 yards, the opening up of a quarry and excavating and crushing 12,000 cubic yards of rock, building of camps and some minor side roads, as well as a very considerable plant charge, amounted to a total cost of $94,000 for about four miles of road—a very excessive amount. To what extent the main office charged in plant afterwards used on other work it was impossible to determine at the time, and no records of it were kept.

A matter of more interest than the total cost is that of unit prices. Some of these were as follows:

Sewers.

Labor		Materials	
Class	Rate	Class	Unit Price
Foremen	$60-125 mo.	4″ pipe, per ft.	$ .08
Pipe Layers	16c-20c hr.	6″ " " "	.12
Laborers	10c-16c hr.	8″ " " "	.20
		10″ " " "	.30
		12″ " " "	.40
		15″ " " "	.54
		18″ " " "	.76½
		24″ " " "	1.46½
		Branches 2½ times these rates.	
		Approx. cost of pipe $= 1/4d^2 + 4$.	

Water Supply.

Labor		Materials.	
Class	Rate	Class	Unit Price
Foremen	$60-125 mo.	Pipe	$ 25.30 per ton of 2000 lbs.
Calkers	16c-30c hr.	Specials	50.00 " " " " "
Laborers	10c-16c hr.	Lead	0.0435 per lb.
		Yarn	0.035 " "
		Hydrants	19.50
		4″ valves	6.25
		6″ "	10.50
		8″ "	15.25
		10″ "	20.75
		12″ "	27.00
		16″ "	70.15
		20″ "	95.00
		36″ "	450.00

Brick Paving.

Labor Class	Rate	Materials Class	Unit Price
Foremen	$60-125 mo.	Brick	$30.00 per M.
Pavers	16c-30c hr.	Cement	2.09 " bbl.
Laborers	10c-16c hr.	Sand	1.00 " cu. yd.

Concrete.

Labor Class	Rate	Materials Class	Unit Price
Foremen	$60-125 mo.	Cement	$ 2.09 per bbl.
Mixers	10c-16c hr.	Sand	1.00 " cu. yd.
Laborers	10c-16c hr.	Stone	1.50 " " "
		Lumber	28.00 " M. ft. B. M.

Earth Excavation.

Labor Class	Rate	Materials Class	Unit Price
Foremen	$60-125 mo.	Lumber	$28.00 M. ft. B. M.
Carpenters	16c-30c hr.	Tools:	
Laborers	10c-16c hr.	Picks	0.28 each
		Shovels	0.32 to .40 each

Rock Excavation.

Labor Class	Rate	Materials Class	Unit Price
Foremen	$60-125 mo.	Coal	$ 6.35 per ton
Steam drillers	16c-30c hr.	Drill steel	0.08 " lb.
Hand drillers	16c hr.	Dynamite	5.62-7.12 case 50 lb.
Engineers	$75-100 mo.	Exploders	34.90 per M.
Firemen	$30 mo.	Fuse	0.004 per ft.
Blacksmiths	16c-30c hr.	Caps	5.25 " M.
Laborers	10c-16c hr.		

In order that there may be contrasted with the excessively high cost of the Savanas road some other work done under favorable conditions, reference may be made to that section running from Caledonia Bridge to near the Zone Boundary, or the macadamized portion within the city limits, which was resurfaced by taking up the original cobblestones, running them through the crusher and putting them back in the shape of macadam, constructing a 20-foot roadway with gutters at an average cost per running foot of $1.49. The total cost per yard of brick paved streets was about $3.50 under the most favorable

conditions, using a concrete foundation, although in the work on the main street, where speed was accomplished at the expense of economy, the cost was in excess of $4.00 per yard. On the concrete streets the cost per square yard was under $2.00 including curbs.

The amount of paving brick first delivered was 3,082.500 at $30 per 1000, which laid 47,570 sq. yds. of street surface, or about 64 brick to the yard, including breakage. There was subsequently bought 1,463,000 brick more, at $27.30, with which the remainder of the Panama City area was completed, as well as the single brick street in Colon.

A description of the installation at Colon and the Zone towns would but repeat on a smaller scale the brief account that has been given of the construction for the principal city. It has been attempted to outline the results accomplished and some of the conditions under which they were done. Many of the difficulties were unavoidable, and such as must always be encountered at the start of a large and new undertaking; some resulted from the lack of knowledge at Washington of tropical conditions, and an unwillingness to give a free hand to those on the work (a condition corrected after a time), and others from ignorant criticism in the public press. Materials were seldom promptly available to complete work as planned. Division heads were frequently hampered by office methods designed for conditions nearer home. As an instance, it was necessary for a long time that each division have its own stores, to avoid their exhaustion by others, and the spectacle was presented of the Municipal Engineering carpenters spiking together 3- by 12-inch planks to make 12- by 12-inch posts, while less than half a mile away the saw mill of the building department was ripping 12- by 12-inch timbers into 3- by 12-inch stuff. To save time manhole heads and covers for sewers were cast at the local foundry from old French scrap, at a labor cost totalling several times their value in the northern market, and bituminous pavement filler ordered without due consideration of the superior advantages of cement grout under the local climatic conditions, was eventually used to stop leaks in the tile roof of the Tivoli Hotel, caused by the lack of knowledge of proper tropical roof construction.

Inadequate arrangements for paying, quartering and feeding laborers made the force short-handed much of the time, and sometimes obliterated it altogether by strikes, when pay day was too long delayed. But throughout, the pressure for prompt results never relaxed, for on the efficient and rapid completion of the labors of the Municipal Division depended the maximum speed of canal construction.

The preliminary work thus outlined occupied to its completion the three and a half years from the taking over of the French Canal Company's property to the end of 1907. It was inaugurated by Mr. Wallace and carried on by Mr. Stevens, and completed by Col. Goethals, and under the jurisdiction of three successive commissions. Its work was effected at a cost sometimes not realized by all who came after. Those on the Isthmus for this period lived and worked in conditions very different from any prevalent since then, or described in accounts of canal work. Comfortable screened houses with furniture, plumbing and electric lights; commissaries, supplied with cold storage; communication between settlements by good roads; club houses, excursion trains, sanitariums and other luxuries which have made the Panama towns the wonder of the swarms of tourists that have visited the Zone in perfect safety and comfort;—these could only come after the labors of the advance guard who worked between and during malarial fever attacks, who saw companions daily carried to the hospital, and kept note of the increasing rows of white crosses in the burial ground and of the piles of pine coffins turned out by the carpenter shop as a side line to keep ahead of the demand, while their wives were living in rooms unscreened because requisitions were delayed, and meanwhile checking American funerals as they passed by, noting the flag-draped coffins.

And through all this time there was an *esprit de corps* very different from the tales that have been written of slackness and panic, supposed (by those who were never there) to have prevailed in the early days. Men worked harder than for many a driving contractor—a case in point being the paving of Panama's main street, when rival gangs racing from opposite ends of the town to be first at the central point, finished half a month before the date set by the chief engineer, not stopping for even a Sunday

rest. The memory of such men as Lester Barton, chief clerk of the Panama residency—who kept to his work seven days in the week and late into the night of each day, because of inadequate help, going to the hospital when he dropped, and returning the instant he could leave, living in crowded unsanitary quarters in the hope of getting a house assignment before long and a chance for a vacation to go home and bring out his promised wife, and who suddenly died of pernicious malaria—did not outlast the completion of their immediate tasks, except among those with whom they toiled and who know of them as typical of many of the early workers, who received no fame but the honor of giving their part to building the foundations for the machinery that has carried to a successful completion the most famous engineering feat of the ages.

Paper No. 6

MUNICIPAL ENGINEERING AND DOMESTIC WATER SUPPLY IN THE CANAL ZONE.

By

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A paper to cover the Municipal Engineering and Domestic Water Supply in the Canal Zone in more than the most general description would greatly exceed the imposed space limitations. Therefore, no attempt will be made by the writer to give in this paper more than a general outline of the municipal and water-supply work that has been accomplished in the Canal Zone and in the cities of Panama and Colon since the beginning of operations on the Panama Canal by the United States Government.

As an intimate and most necessary part of the general sanitary plans for cleaning up the Isthmus of Panama and making it habitable to North Americans, it may be stated that the municipal engineering work began immediately following the advent of the first American engineers in Colon in June, 1904. The necessity for designing and constructing suitable water-supply and sewer systems, for laying out and building streets and roads in all the small towns of the Canal Zone and in the cities of Colon and Panama, was considered a paramount one. Every effort was directed toward accomplishing this end in the shortest possible time, and the magnitude of this work will be realized when it is remembered that in June, 1904, there was not a paved or macadamized street in the cities of Colon and Panama; not a road or street, fit to be termed such, in the numerous towns in the Canal Zone, excepting within the Ancon Hospital grounds, and, with one or two exceptions, not a sewer or water system on the entire Isthmus.

By the end of the year 1906 these conditions were changed, to the extent that the cities of Colon and Panama had been sewered; streets paved with brick or macadam or both; and reservoirs had been built and water delivered into the newly-laid mains. By this time water and sewer systems had also been installed in the principal towns along the line of the Canal and miles of macadam roads had been constructed.

Up to this time, and continuing until July 1, 1908, all municipal work was carried on under one head in charge of a Division of Municipal Engineering. Upon this latter date, the Canal construction work was divided into three main divisions, viz., Atlantic, Central and Pacific, and all municipal work lying within the territorial limits of these divisions was placed in charge of the division heads. This applied to all work within the Canal Zone and lying without the limits of the cities of Colon and Panama. The work within these two cities was made a separate and distinct section and placed under a superintendent at the head of a Division of Public Works.

Prior to July 1, 1908, all sanitary work requiring the construction of drainage ditches, the draining of swamps, etc., was carried on by the forces of the Sanitary Department. Subsequent to this date and continuing to the present, this work became a part of the municipal engineering work, to the extent that the municipal forces located and constructed the ditches, drained swamps, etc., upon the request of the Sanitary Department.

In July, 1913, all municipal work within the Canal Zone and also that within the cities of Colon and Panama was withdrawn from the three main divisions and from the Division of Public Works, which was abolished, and consolidated to form a new Division of Municipal Engineering. After April 1, 1914, this division became a part of the Department of Operation and Maintenance of the Canal, and as such becomes, after the completion of new construction work described below, a strictly maintenance division, covering the operation of pumping stations, water purification plants, water distribution systems and sewers, and road and street maintenance throughout the Canal Zone and in the cities of Colon and Panama.

At this point it may be pertinent to state that all municipal

work within the limits of the cities of Colon and Panama has been done by the forces of the United States Government, the original cost to be ultimately paid by the Panama Republic at the expiration of a certain term of years.

All house water connections in these two cities are metered and the receipts from water rentals are collected by the Municipal Division and applied to the cost of maintaining the streets, sewers and water systems. The city of Colon, having a population of approximately 17,000, has at present 1000 metered connections. The net rate charged is 40c. per thousand gallons (3785 litres). The net per capita consumption per day, exclusive of public-service water, is approximately 40 gallons (151.4 litres). In Panama, a city of 55,000, there are 2300 metered connections. The net rate charged is 25 cents per thousand gallons (3785 litres). The net per capita consumption per day is 40 gallons (151.4 litres), exclusive of public-service water. The total consumption, based per capita in Colon, is 71 gallons (268.7 litres), and in Panama 65 gallons (246 litres).

STREET AND ROAD WORK.

In general, the street and road construction on the Isthmus may be divided into the following classifications: (1) Brick pavement, concrete base; (2) concrete pavement; (3) macadam, water-bound; (4) macadam, water-bound, oiled surface; (5) asphalt concrete, macadam base; (6) gravel roads.

The brick and concrete street pavements are, with few exceptions, confined to the cities of Colon and Panama. The remaining types are found in all the towns of the Canal Zone, and also in the city of Panama.

The brick and concrete pavements were placed in the streets carrying the heaviest traffic, and may, in general, be said to have given the most satisfaction and to have been the least expensive to maintain.

Typical cross-sections of the various types of streets and roads are shown on Plate I.

It may be stated that water-bound macadam streets and roads have been, and are, the standard form of construction on the Isthmus. The use of crushed rock followed, naturally, the

opening of quarries for the production of rock used for the principal masonry structures of the Canal. Further, it was, and is at this writing, the aim to get streets and roads opened and finished for service in the least practicable time, in order to meet the immediate needs of rapidly built towns that grew

Fig. 1. Water-bound Macadam Road after Three Years of Service without Repairs.

into existence in a few days with the opening of work at some important center on the Canal. Some of these towns flourished for a few years, perhaps not to exceed six, and disappeared with the completion of the Canal and the creation of the Gatun Lake.

The streets and roads were laid with crushed rock as it came from the crushers operating primarily and exclusively, as far as size of stone was concerned, for concrete materials only.

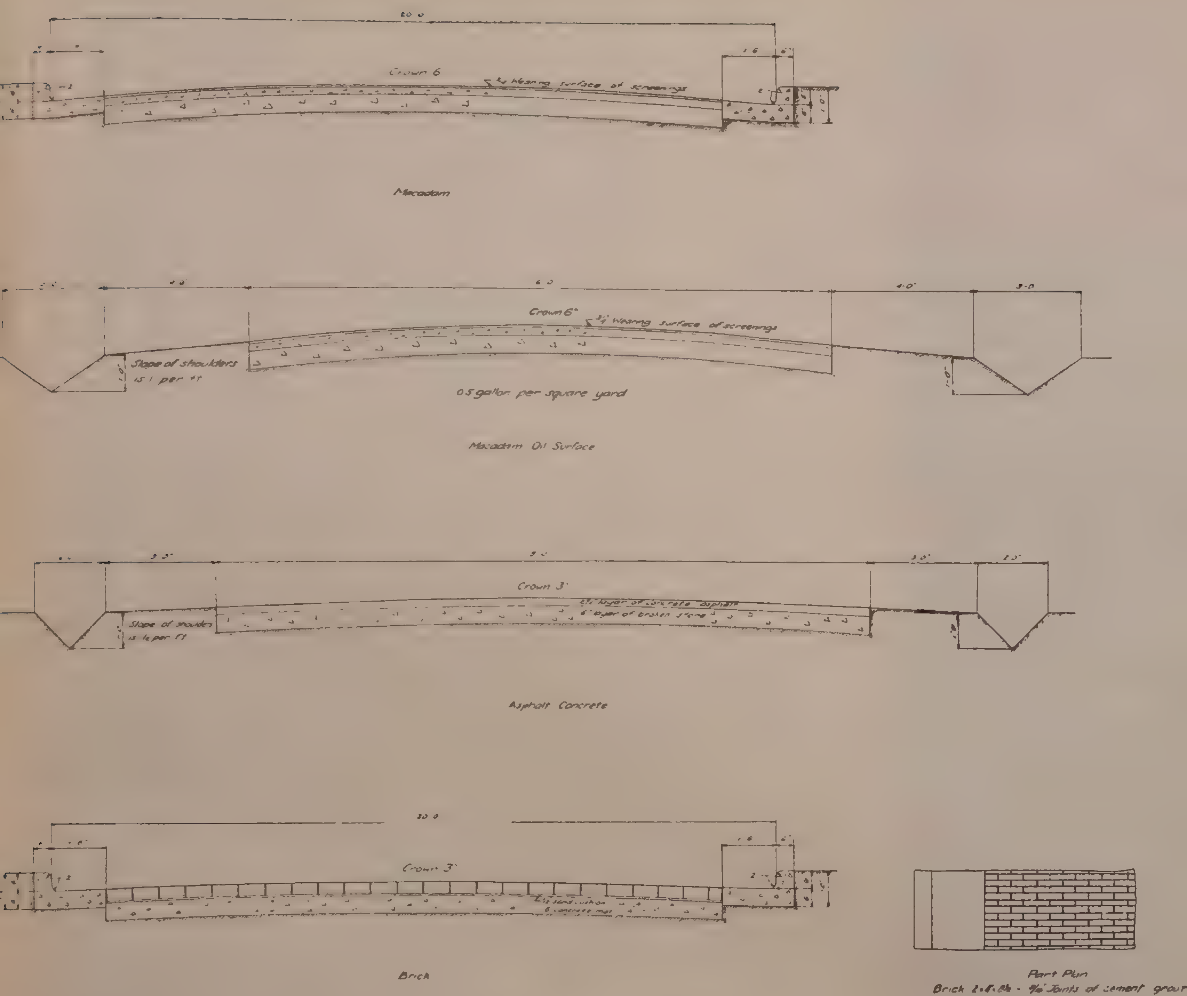
With the exception of the street and road work done prior to 1908, the crushed rock for the streets of Colon, Cristobal, New Gatun and Gatun was obtained from the Porto Bello crushers. The run of the crusher, screened to a 3-inch (76.2 mm) size was the only grade available and was placed, as it came on the road or street, in a single layer 6 inches to 9 inches (152 mm to 228 mm) in depth. Sufficient dust was extracted to form a dressing and, following a thorough rolling by twelve- to fifteen-ton steam rollers, the surface was ready for traffic.

The Porto Bello rock is more or less remarkable in its suitableness for road building. It is an andesite without planes of cleavage and when rolled into a subgrade, without any other treatment than a dust dressing and sprinkling, it forms a closely semi-cemented surface that may be said never to ravel. It becomes rough due to the wearing away of the dressing, but in few instances does it give way and break up, as is a common characteristic of water-bound macadam roads. Figure 1 gives an excellent idea of the appearance of the surface of a road constructed with this rock, after 3 years of more or less heavy traffic under both self-propelled and horse-drawn vehicles. No repairs of any nature have been made to the road shown in this view, since the rock was first laid.

For the construction of streets and roads south of Gatun, and particularly in the towns of Empire, Culebra, Pedro Miguel, Corozal, Ancon, Balboa and the city of Panama, crushed rock from the Ancon quarry is used. This quarry was opened and the rock crushed primarily for the construction of the locks and accessory structures at the southern end of the Canal. This rock is graded into two classes, Nos. 1 and 2. No. 1 rock covers any size held on a 2-inch (50.8 mm) screen and up to pieces as large as 6 inches (152 mm); No. 2, any size passing a 2-inch (50.8 mm) screen and having the fine dust removed. The rock is a rhyolite and breaks along many lines of cleavage, and possesses no cementing or matting characteristics when rolled under conditions obtaining in road construction.

The water-bound macadam roads and streets built with the above described rock presented difficulties in developing a wearing surface that would not ravel under traffic. The roads

Fig 2 Water-bound Macadam Street Constructed with Ancon Quarry Rock.



Note: All sections are parabola

Plate I. Typical Sections of Streets.

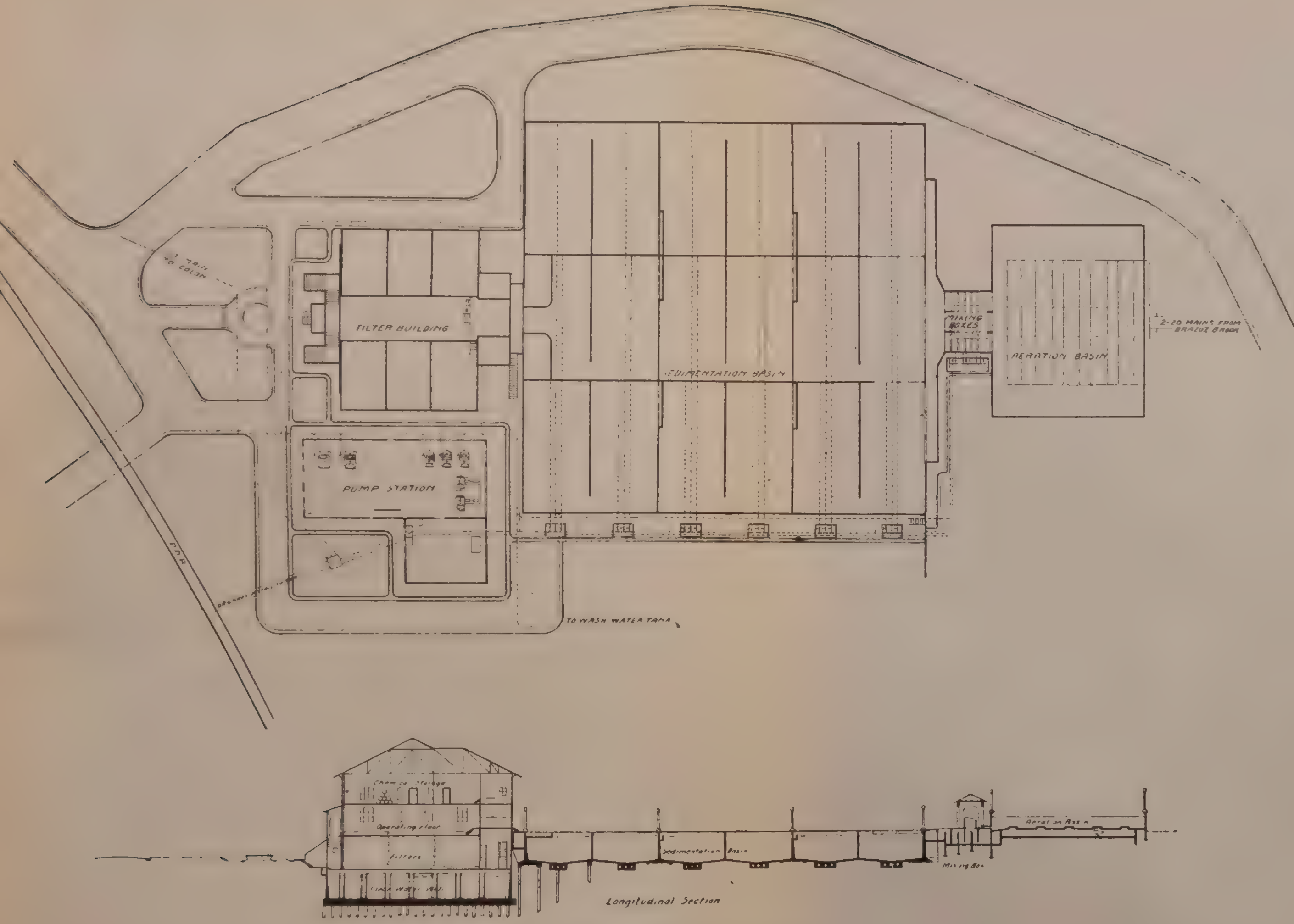


Plate III. Water Purification Plant at Mount Hope.

as built have been layed with a 6-inch (152 mm) thickness of No. 1 rock and a 2- to 2½-inch (50.8 to 63.5 mm) thickness of No. 2 rock. A top dressing 1 inch (25 mm) in thickness of the dust and screenings from the No. 2 rock completed the surface. This character of road or street invariably requires re-dressing and re-rolling within a short time after first opening to traffic, and it usually requires a second thorough rolling before it may be considered satisfactory. As might be expected, the use of this class of material results in heavy maintenance costs. The first cost, however, is comparatively low—75 cents a cubic yard (0.765 cubic meters) for the rock of either class and 50 cents per cubic yard (0.765 cubic meters) for the screenings. Figure 2 gives a typical view of a street constructed of these materials.

The tendency of the above described roads and streets to ravel and to become excessively dusty, during dry-season months, led to the use of crude California fuel oil applied cold to the road surface after the dressing had been thoroughly rolled. This is an additional instance of making use of material, for road and street work, the character of which was primarily determined by the needs of work in connection with Canal construction other than road and street work.

Best results have been realized from the use of approximately one-half gallon (1.9 litres) of crude oil to each square yard (0.836 square meters) of surface. Roads and streets treated in this manner usually require re-surfacing once each year. Figure 3 gives a typical view of this type of road and street after six months of traffic.

In the districts where sea water is readily available for road or street sprinkling, it has been the practice to make use of it for sprinkling during the dry-season months, usually December to May. The rapid evaporation of the water leaves a certain amount of salt on the road surface, and it was found that sprinkling once in three days sufficed to bind the loose, fine dust on the surface to such an extent that little ravelling takes place and the dust nuisance is at the same time eliminated.

In the building of the new, permanent town of Balboa, where will be housed a large percentage of the American employees on the operating force of the Canal, it was decided to

Fig. 3. Oiled-Surface Macadam Street after Six Months' Service.

adopt the asphalt-concrete type of construction for the streets. This work is at the present writing in progress. The asphaltic concrete will be laid on a water-bound macadam base.

The total amount of different classes of streets and roads, in miles of length, constructed and maintained by the Municipal Division since the occupation of the Americans, is given in the following table:

(1)	Brick Pavements, concrete base	5.11	miles	(8.2 km)
(2)	Concrete Pavement	2.50	"	(4.1 ")
(3)	Macadam, water-bound	82.3	"	(132.7 ")
(4)	Macadam, water-bound, oiled surface	22.0	"	(35.5 ")
(5)	Gravel Road	2.9	"	(4.7 ")
	Total	114.81	"	(185.2 ")

SEWERS.

The construction of sewer and drainage systems was carried along simultaneously with the street, road and water-supply work in all the towns of the Canal Zone and in the cities of Colon and Panama.

With the exception of the city of Colon, the sewage from all towns in the Canal Zone and from Panama City is disposed of by gravity flow through laterals to main outfalls, finally emptying into the Canal, or, as in the instance of Panama City, into the Bay of Panama. This work presented no unusual problems and was simply a matter of getting the laterals and outfalls into service with the least practicable delay.

In the case of the city of Colon, the sewage disposal was somewhat more complicated, in that the elevation of the streets is little above mean sea-level. The maximum elevation is approximately 8.0 feet (2.44 meters) and the minimum 2.5 feet (762 mm). This condition required the pumping of all sewage, and, accordingly, a sewage pumping station was installed near the center of the city.

This station comprises a sump 30 feet by 30 feet (9.14 meters by 9.14 meters) in plan, with its invert 20 feet (6.096 meters) below sea-level. The roof of this sump, forming the floor for carrying the pumps, was placed at elevation 8.72 feet

(2.65 meters) below sea-level and was designed for full upward static pressure due to sewage standing at sea-level.

The pumping equipment consists of two single-stage, volute, centrifugal pumps, dredging type, direct connected to induction motors. Each pump has a capacity of 2500 gallons (9462 litres) per minute against a total head of 65 feet (19.81 meters). The discharge line from these pumps is a 12-inch (304.8 mm) diameter cast-iron main, which discharges into an arm of Manzanillo Bay, to the south of the city and distant from the station about 4000 feet (1.22 km).

Approximately 2,000,000 gallons (7,570,000 litres) of sewage per day of 24 hours were handled by these pumps during the year ending June 1, 1914. It will be noted that this amount is in excess of the total consumption of water in the city, which is readily explained by the statement that although separate drainage and sewer systems are in use, a large amount of ground water finds its way into the sewers through poor joint work done at the beginning of the construction work, when labor was of practically negligible ability and almost useless.

Both separate and combined sewage and drainage systems have been installed on the Isthmus. In the city of Panama, the original installations were on the combined system, and this policy was continued up to the year 1913, since which time the policy has been, so far as possible, to install separate systems where practicable.

In the city of Colon, a separate system was installed in the beginning, and, in general, has given better satisfaction than the combined systems in Panama and in the towns along the line of the Canal.

The torrential rain-fall during part of the year requires drainage systems and storm sewers of comparatively enormous cross-section, in order to provide reasonably rapid run-off. Beginning in December and lasting generally to May, the rainfall drops almost to zero. Under the combined drainage system, this condition results, during the rainy season, in the flooding of sewers, and during the dry season in offensive odors, due to lack of sufficient water to flush properly the comparatively large sewers. In the city of Panama, there are periods during the dry season when, even though a great deal of water is used

in attempts to flush properly the sewers, many complaints arise because of offensive odors emanating from the sewers. In the city of Colon and in the towns along the line of the Canal where the separate systems are used, this condition does not arise.

The estimated total number of miles of vitrified sewers and drains of all sizes and character, laid and maintained in the towns of the Canal Zone and the cities of Colon and Panama, amounts to 73 miles (117.5 k). The total length of reinforced-concrete storm sewers amounts to 4 miles (6.4 k).

DOMESTIC WATER SUPPLY.

From the beginning of the work on the Canal by the American forces, the providing of adequate and suitable water, for both domestic and industrial use, has been by far the most interesting and difficult problem handled by the Municipal Engineering Division.

The first work undertaken in 1904 was the placing of a gravity supply in the city of Panama and in the towns south of Culebra. The French canal company had constructed a reservoir on the Rio Grande, a short distance south of Culebra. The masonry dam forming the impounding reservoir was raised 17 feet (5.18 meters), thus placing the elevation of its spillway at 235 feet (71.6 meters) above mean sea-level. The usable volume of the reservoir, without flash-boards, amounts to 315,000,000 gallons (1,193,000,000 litres), and the tributary watershed is three square miles (777.0 hectares) in area.

A 16-inch (406.4 mm) diameter cast-iron bell and spigot main was laid from this reservoir to Ancon, at the city limits of Panama, a distance of 52,000 feet (15.85 km). On a detached hill, at this point, was constructed a concrete receiving reservoir, having a capacity of 1,000,000 gallons (3,785,430 litres), at an elevation of 135 feet (41.2 meters) above mean sea-level. This system provided an adequate supply for points of consumption up to elevation 100 ft. (30.48 meters). For points above this elevation, small steam-driven pumps were installed as boosters, pumping into small tanks on the side of Ancon hill at elevation 300 ft. (91.44 meters).

In 1906, pressure filters of the Continental Jewel type were installed at Ancon; at first three units of 500,000 gallons

(1,897,720 litres) daily capacity each, then later two additional units of the same capacity each. The water was treated with crystal alum, without sedimentation prior to entering the filters, and the resulting effluent showed some reduction in color, turbidity and iron.

In 1911, the increasing water demands made necessary the laying of an additional main from Rio Grande, and a 20-inch (508 mm) diameter cast-iron line was placed in service early in 1912. The Rio Grande supply became by this time inadequate, and pumping from the Cocoli River directly into the mains was resorted to in order to make up the deficiency. The Cocoli River is located directly west of the Miraflores locks and about 6 miles (9.65 km.) south of Rio Grande.

The Rio Grande watershed was uninhabited and was made a reserve, so that the possibility of contamination was eliminated. The physical character of this water, covering a period of six months—November, 1913 to April, 1914, both inclusive —follows:

Monthly Analyses—Rio Grande Reservoir.

Month	Odor	Taste	Turbidity	Color	Alkalinity	Oxygen Consumed	Chlorine	Iron	Free CO_2	Bacteria per c. c. Agar 38 deg. C.	B. Coli percent 10 c. c.	B. Coli percent 1 c. c.
*Nov. 13		Earthy	10	65	56	5.0	7.7	0.5	4.0	1300	Pos.	Neg.
Dec. 13	Earthy	0	Slight	65	60	2.8	5.0	0.2	2.0	280	"	"
Jan. 14	0	0	18	55	80	3.7	......	0.3	2.5	200	Neg.	"
Feb. 14	0	0	5	35	65	4.1	6.2	0.1	2.0	1100	"	"
Mch. 14	0	Veg.	5	35	72	7.3	4.0	0.8	0.0	560	Pos.	"
Apr. 14	Veg. "	"	5	20	68	5.6	5.0	0.25	2.0	400	Neg.	"

The above water-supply system continued in use until the approaching completion of the Miraflores locks and the creation of the Miraflores Lake, in July, 1913, when the question of an entirely new and permanent water supply was taken up, resulting in the project under construction at the present time, and described below under the section—"Permanent Water Supply for Southern End of Panama Canal".

* Diluted with water from Miraflores Lake.

The water supply for the city of Colon and the towns of Cristobal and Mount Hope, at the northern end of the Canal, was second only in importance to that for the southern end of the Canal. This work was taken up in 1905 and resulted in the construction of an earthen dam and the formation of a reservoir on Brazos Brook, a stream located about one and one-half miles (2.4 km.) south of Mount Hope. This dam is about 45 feet (13.7 meters) in height, 2810 feet (856 meters) in length, and impounds 650,000,000 gallons (2,460,000,000 litres) of water. The elevation of the spillway is 50 feet (15.24 meters) above mean sea-level. From the reservoir to Mount Hope was laid a 20-inch (50.8 cm) diameter bell and spigot main, where was installed a steam pumping-station and pressure filter-plant of 4 units, similar to the one described above for Panama City. From this station, a 20-inch (508 mm) main was laid to Colon, about two miles (3.22 km.) distant, and the water flowing by gravity from Brazos Brook to the pumping station was pumped directly into the mains, through the pressure filters. A little later a 300,000-gallon (1,135,632 litres) capacity sedimentation basin was constructed, and the water, after having been given a dose of aluminum sulphate and two to three hours' sedimentation, was passed to the filters. Just prior to this, a 450,000-gallon (1,705,000 litres) capacity steel stand-pipe was erected immediately above the pump station and used as a surge tank and reserve supply.

The character of the Brazos Brook water, based on an average for a period of six months (March, April and May, 1913 and 1914), is given below:

Chemical Analysis of Raw Water from Brazos Brook Reservoir.
Parts per Million.

Period	Turbidity	Color	Alkalinity	Chlorine	Oxygen Consumed	Nitrates	Iron	Free CO_2	Total Solids	Loss on Ignition.
Average for six months	25	50	34	6.7	4.6	Trace	1.0	3.7	98	31

During the rainy season months, the run-off from the watershed of Brazos Brook was sufficient to provide for all demands, but as the daily consumption approached 3,000,000 gal-

lons (11,356,320 litres), the dry-season flow and the storage became inadequate and resort had to be made to pumping from a supplementary supply.

The above described system continued until 1912, when it became necessary to enlarge and provide a permanent, adequate and suitable supply. This resulted in the construction of the present water works and purification plant described below.

The water supplies for the towns of Culebra, Empire and Gorgona were next in importance, and work was commenced early in 1906 and 1907 on the construction of two reservoirs, one on the Camacho, a stream in the hills back of Empire, and one on the Carabali, a stream near Gorgona.

The Camacho dam is an earthen structure with a concrete core wall. Its length on crest is 320 feet (97.5 meters); the maximum height is about 70 feet (21.33 meters), and it impounds 296,000,000 gallons (1,120,360,000 litres). The water from this reservoir flows by gravity to a steam pumping-station, and is then pumped directly into the mains. This supply early became inadequate, as the construction work in the Culebra cut expanded, and resort was had to pumping both from the Rio Grande reservoir and the Chagres River at Gamboa.

The reservoir for supplying water to the town of Gorgona was constructed in 1906. This dam was smaller than that at Camacho, being approximately 30 feet (9.14 meters) in height and impounding 80,000,000 gallons (302,835,200 litres). A pumping station was necessary at this point also, and by 1909 the Culebra, Empire and Gorgona systems were made continuous by the opening up of the intermediate towns of Bas Obispo and Las Cascadas. During the height of the work in the Culebra cut, these water supplies, supplemented by the Rio Grande and Chagres River pumping stations, furnished in the neighborhood of 4,000,000 gallons (15,147,600 litres) daily.

The water from the reservoirs was high in color, contained iron as high as 2.5 parts per million and at times was turbid to the extent of 50 parts per million. It was free from contamination as it left the reservoirs, but was not agreeable to the taste. This, combined with the possibility of contamination after reaching the mains, due to the mingling of the Chagres River water as a supplementary supply, resulted in the establishing of small

local steam sterilizing plants at Empire, Las Cascadas, Bas Obispo and Gorgona. Sufficient water was sterilized at these plants to provide a safe and more desirable drinking water, which was delivered by carts to the consumer.

Today Gorgona and Bas Obispo have gone out of existence, by reason of the completion of the Canal work, and in a short time Culebra, Empire, and possibly Las Cascadas, will follow, with the abandonment of the reservoirs. As each town is demolished, the water mains are removed and used again in the extensions at the southern end of the Canal, where concentration is taking place.

The creation of the town of Gatun made necessary the construction of a water works for this place, and while at the beginning of 1907 water from the Chagres River was pumped directly into the mains and drinking water was supplied by cart delivery after sterilization, as described above, the design and construction of a permanent reservoir, purification plant and pumping station was early taken up and finally completed and placed in service in January, 1911. This plant is described in detail below.

AGUA CLARA WATER WORKS AND PURIFICATION PLANT.

From 1906 to 1908 the supply for Gatun was, as stated, obtained by pumping Chagres River water directly into the mains. In 1908 a 400,000-gallon (1,514,176 litres) tower tank was erected and placed in service as a surge tank and reserve. Following this, studies for a permanent supply were taken up, and it was decided to construct a reservoir on a creek named Agua Clara, about 1½ miles (2.42 km.) northeast of the town, install electric-driven pumps and later a purification plant.

The Agua Clara dam, as constructed, is a composite earth and rock-fill structure, without core wall. The downstream, or rock-fill, side was dumped into place from cars. The upstream side, consisting of selected clay, was placed in layers by scraper method.

The extreme height is 55 feet (16.72 meters); crest length, 650 feet (198.1 meters); upstream slopes, 1 on 3½; downstream slopes, 1 on 1. The volume of water impounded, with spillway crest 68 feet (20.7 meters) above sea-level, is 615,000,000 gallons

(2,328,000,000 litres). The area of the watershed is one square mile (259 hectares); the average yearly rainfall on this shed is 135 inches (3.42 meters).

The character of the water from this reservoir, based on an average for a period of six months, December, 1913, to May, 1914, inclusive, is shown below:

Parts per Million.

Period	Turbidity	Color	Alkalinity	Chlorine	Oxygen Consumed	Nitrates	Iron	Free CO_2	Total Solids	Loss on Ignition
Average for six months	25	85	23	6.4	5.2	Trace	1.2	5.1	95	54

Prior to the construction of the purification plants as a part of the Agua Clara water works, the water from the gate house flowed by gravity, through a 16-inch (406 mm) main, directly into the suction side of pumps in the pump station located near the downstream toe of the dam.

This pump station is a single-story concrete building, housing two 3-stage, direct-connected, motor-driven, centrifugal pumps. These pumps have a capacity of 1400 gallons (5299 litres) per minute against a total head of 300 feet (91.4 meters). The motors are 175 hp., induction, slip-ring type, operating on 3-phase, 25-cycle, 440-volt current. The water reaches the general distributing system of Gatun through a 12-inch (304.8 mm) cast-iron main, off which is connected the 400,000-gallon (1,514,176 litres) capacity steel tower tank referred to above.

In the latter part of 1910, it was decided that, in view of the permanency of Gatun as a town, steps should be taken to treat the water, with a view to the elimination of objectionable iron, color, taste and turbidity present at all times in varying degrees. The design of a plant for this purpose was undertaken by the writer, and following a more or less extensive series of experiments, the so-called rapid gravity mechanical type of filter was adopted. The following description covers the plant as built and now in operation.

Plate II gives a plan, section and elevation of the entire plant, including pumping station, clear-water well and labora-

Fig. 4. Agua Clara Purification Plant, Gatun Water System.

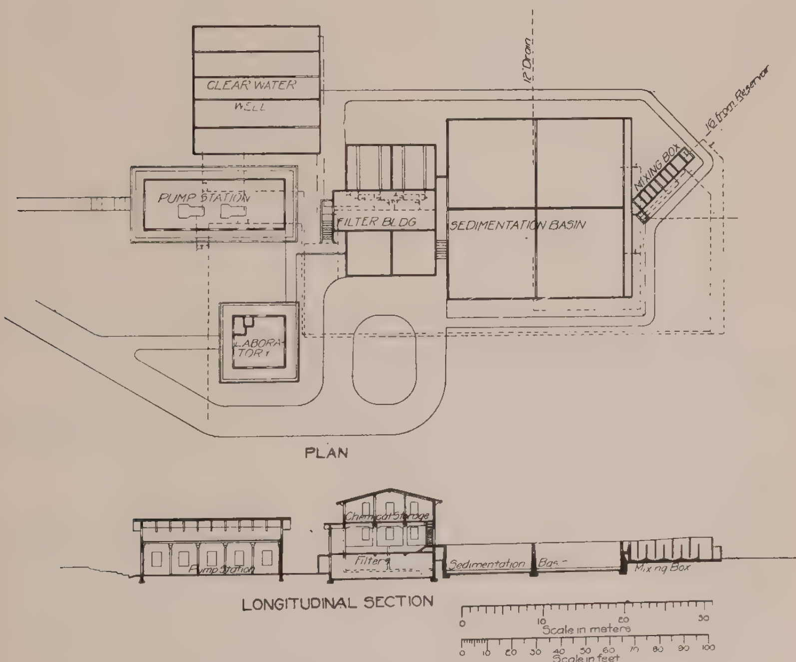


Plate II. Water Purification Plant at Agua Clara.

tory (see Figure 4). The purification plant includes a mixing chamber 5 ft. x 30 ft. 6 in. (1.52 m. by 9.30 m.), divided into 8 compartments by walls forming submerged and overfall weirs; a sedimentation basin 70 ft. 6 in. x 70 ft. 6 in. x 10 ft. (21.5 x 21.5 x 3.05 m); a filter building containing 4 filter beds 17 ft. x 17 ft. x 9 ft. (5.18 x 5.18 x 2.73 meters) on the ground floor, and chemical mixing tanks and storage on the second floor; a clear-water basin, 225,000 gallons (851,625 litres) capacity, detached from the filter building; a wash-water tank of 20,000 gallons (75,700 litres) capacity, located on a hill about 500 feet (152.4 meters) distant; and a fully equipped laboratory.

The plant is designed for a maximum capacity of 2.500,000 gallons (9,462,500 litres) per day of 24 hours. The filters operate without negative head at a rate of from 100,000,000 to 125.000,000 gallons (935 to 1170 million litres per hectare) per acre per day. The under-drainage system consists of 2-inch (50.8 mm) diameter galvanized-iron pipes, perforated on the lower side by 7/32-inch (5.5 mm) holes spaced on 3-inch (76.3 mm) centers. The pipes are spaced on 6-inch (152.4 mm) centers. The combined wash-water and air system is used. The wash rate averages 9 gallons per square foot (366 litres per square meter) of area per minute. The air is furnished by motor-driven air compressors, located in the pump station. These machines deliver the air at 100 lbs. per square inch (7.03 kg. per sq. cm.) pressure to a large receiver, from which the air is drawn for agitation in the filter bed at about 5 lbs. per square inch (.35 kg. per sq. cm.) pressure.

The filter medium consists of a layer of gravel 9 inches (228.6 mm) in depth, having a mean size of ⅝ inch (16 mm), and a 3-inch (76.2 mm) layer having a mean size of from ¼ inch to ⅜ inch (6.3 to 9.5 mm). Above this is placed a layer of sand 30 inches (762 mm) in depth, having a mean effective size of 0.35 mm and a uniformity coefficient of 1.6.

The sedimentation basin is operated on the continuous principle and gives three hours' sedimentation at maximum output of filters.

A large percentage of the iron content of the water is in solution, and experiments with compressed air, as a substitute for natural aeration, indicated that aeration, as a preliminary

treatment prior to the application of alumina sulphate, would throw down an appreciable percentage of the iron, and thus result in a saving in the amount of alum required to remove the color. This idea was followed out in the design of the Mt. Hope plant, described below, and, at times, compressed air injected into the water at Agua Clara is of considerable assistance as a crude pre-treatment.

The following table gives the results of operation of this plant covering a period of six months ending May, 1914:

Month	Gallons Filtered	Percent Wash Water	ALUM		Bacteria per c. c. Agar 38 degs. C.		Times B. Coli present			
							Raw		Filtered	
			Pounds	Grs. per gal.	Raw	Filtered	10 c. c.	1 c. c.	10 c. c.	1 c. c.
Dec., 1913	45,007,000	6.0	12,655	1.9	380	100	13	1	1	0
Jan., 1914	41,482,000	5.0	12,152	2.0	207	120	17	9	2	0
Feb., 1914	35,839,000	6.0	14,443	2.7	357	175	12	4	0	0
Mch., 1914	43,402,000	6.2	16,585	2.5	580	360	19	0	0	0
Apr., 1914	40,598,000	5.6	16,550	2.8	524	358	15	8	3	0
May, 1914	44,049,000	6.2	15,987	2.45	84	*191	13	6	1	0

The total cost of the Agua Clara Water Works, including reservoir, was $250,000.00.

NEW MOUNT HOPE WATER WORKS AND PURIFICATION PLANT.

As stated above, the Brazos Brook reservoir supply had by 1911 become inadequate, and the original pumping plant and pressure filter plant at Mount Hope had become unsuited as a part of the permanent water works for Colon and Cristobal.

The design and construction of an entirely new plant was taken up by the writer in the latter part of 1911, and in February, 1914, the plant as described below was placed in service.

The upper reaches of the Brazos Brook reservoir are separated at several points from the Gatun Lake area by high, narrow ridges. For the purpose of supplementing the supply from the watershed of the Brazos Brook, a tunnel 700 feet (213.4 meters) in length was driven through the ridge into the Gatun Lake at an elevation of 76 feet (23.2 meters), or 3 feet (0.915

* Undergrowths—filters being overhauled.

meters) below low water in the lake. This work was done before the level of water in Gatun lake was above elevation 50 (15.24 meters). The tunnel is in rock throughout its length.

In this tunnel was laid a 20-inch (508 mm) diameter cast-iron main, ending on the Gatun Lake side in a concrete gate house and screen chamber. The head of the tunnel was filled with concrete for a distance of 30 feet (9.14 meters) back towards Brazos Brook, and the Brazos Brook portal was also sealed with concrete. This pipe was extended down to the level of the water in the Brazos Brook reservoir and ended in a control chamber. In this control chamber was placed a 16-inch (406.4 mm) hydraulic valve, actuated by a float-operated piston valve automatically admitting water to the 16-inch (406.4 mm) valve cylinder, either opening or closing it as the surface level in the reservoir rose or fell. By this means is provided an automatically controlled and unlimited supplementary supply to the Brazos Brook supply.

The new pump station and purification plant is located immediately adjacent to the old plant at Mt. Hope, referred to on page 13, and about 6100 feet (1.86 km.) distant from the reservoir at Brazos Brook.

The plant is designed for a maximum capacity of 7,500,000 gallons (28,387,500 litres) per day, and to provide for this an additional 20-inch (508 mm) cast-iron main was laid from the reservoir to the plant. The limited head available to and through the different parts of the plant added many difficulties to the design.

The purification plant consists of aeration basin, head-house, mixing chambers, sedimentation basin, and filter building containing clear-water basin, filters, solution tanks, alum-storage rooms and laboratory and quarters.

Immediately adjacent to the filter building is located the pumping station. The equipment in the station consists of three 2000-gallon (7570 litres) per minute, direct-connected, centrifugal pumps, motor driven; two 3000-gallon (11,355 litres) per minute fire pumps, same type; and two motor gear-driven air compressors, straight-line type, with air receivers. The pump motors operate on 2200-volt, 3-phase, 25-cycle current, the air compressors on 220-volt current.

The 2000-gallon (7570 litres) pumps are designed for maintaining a 50-lb. per square inch (3.5 kg. per sq. cm.) pressure in the mains for regular service. The fire pumps are designed to maintain 100 lbs. per square inch (7.03 kg. per sq. cm.) pressure under fire conditions.

These pumps take their water from a sump beneath the floor of the station, which is connected by a culvert with the clear-water basin beneath the filter building. The pumps operate directly on the main, and the 450,000-gallon (1,705,000 litres) tank referred to on page 13 is used for wash-water supply to the filters and for reserve, in addition to the clear-water basin supply.

The aeration basin, 66 x 84 ft. (20.2 x 25.6 m) in plan, contains 85 movable cone nozzles, connected in 5 banks of 17 nozzles each, through main-line horizontal shafting and rocker arms, to float stems, leading down through the floor of the basin to floats resting in a float box running the entire length of the basin. This float box is connected with the receiving chamber at the head of the filters in such a way that the water level at both places stands at the same elevation. The floats, rising and falling, open or close the cones, and thus automatically meet the water fluctuations in the output from the filters, due to units going in or out of service.

The water is thrown out from the surface of the cones at an angle of 30 degrees and, breaking into fine spray, falls to the floor of the aeration basin.

The head-house and mixing chamber are placed between the sedimentation basin and the aeration basin, and the water receives its aluminum sulphate as it passes from the aeration basin over weirs. The head-house contains the measuring devices for applying the alum in proper amounts. The solution is mixed in tanks located on the third floor of the filter building and flows to the head-house by gravity.

The mixing chambers comprise 3 baffled compartments 9 ft. x 20 ft. (2.74 x 6.09 meters) in length, each compartment corresponding to a main division of the sedimentation basin.

The sedimentation basin is 172 x 172 feet (52.4 x 52.4 meters) in plan by 13 ft. 6 in. (4.11 meters) in depth and has a capacity of 2,500,000 gallons (9,462,500 litres). It is operated on

the continuous plan and gives 8 hours' sedimentation at full capacity of filters. Lack of space forbids discussing the details of operation of this basin.

The filter building is located at the opposite end of the sedimentation basin from the mixing chamber and is approximately 64 ft. x 72 ft. 6 in. (19.5 x 22.1 meters) in plan.

The clear-water basin, holding 520,000 gallons (1,968,200 litres), forms the basement and foundation for the building. Located directly over this basin and supported on columns are the six filter beds, ranged 3 on each side of the pipe gallery below and operating floor above.

Each filter is 18 ft. 8 in. x 27 ft. 6 in. (5.7 x 8.38 meters) in plan by 10 ft. 3 in. (3.13 meters) in depth, and is laid with a gravel depth of 21 inches (533 mm) and a sand depth of 30 inches (762 mm). Commencing at the bottom of the filter there is a 10-inch-thick (250 mm) layer of gravel having a mean size of approximately one inch (25 mm); next above this is a layer 7 inches (177.8 mm) thick having a mean size of ½ to ⅝ inch (12.7 to 16 mm) and above this layer is laid 4 inches (101.6 mm) of fine gravel having an effective size from ⅛ to ¼ inch (3.2 to 6.4 mm). The sand rests directly on this upper layer of fine gravel without separating screens. The mean effective size of the sand is 0.42 mm and uniformity coefficient 1.6.

The under-drainage system is similar to that placed in the Agua Clara filters, and is figured for 11 gallons per square foot (447 litres per square meter) of filtering surface per minute, wash-water rate. Air is used for agitation of the bed as a part of the washing operation. All valves are hydraulically actuated and operated from slate-top operating tables. The filters may be operated with or without negative head. The wash-water troughs are of concrete, and comprise one main, centrally located trough with 4 laterals on each side. Electric light indication is used for indicating filters in or out of service or ready for cleaning. Effluent controllers are specially designed, simple open type, and discharge through bronze orifices in the floor of the pipe gallery into the clear-water basin.

The third floor over the filters carries two solution mixing tanks, and provides nine months' storage of alum. On this floor is also located a laboratory, equipped for the simple analyses

of water, and off this room are provided living quarters for the chemist in charge of operation. The following table gives the results of the first three months of operation of this plant—March, April and May, 1914:

March, 1914

Gallons treated	Gallons pumped	Wash water	Gallons filtered	% Wash water
119,825,000	103,696,000	13,073,000	116,769,000	11.2

Filters washed	Ave. minutes wash water	Alum Pounds	Alum Grs. gal.	Ave. filter hrs. per day	Ave. No. filters service
322	7.0	32,250	1.88	88.8	3.7

Ave. length run between washings	Ave. percent of time filters in service	
8.5 hrs.	60.2	Rate of all filters 100,000,000 gallons per acre.

April, 1914

Gallons treated	Gallons pumped	Wash water	Gallons filtered	% Wash water
126,351,000	111,218,000	11,800,000	123,018,000	9.6

Filters washed	Ave. minutes wash water	Alum Pounds	Alum Grs. gal.	Ave. filter hrs. per day	Ave. No. filters service
291	8.0	41,515	2.33	81.6	3.4

Ave. length run between washings	Ave. percent of time filters in service	
8.7 hrs.	58.2	Rate of all filters 104.4 million gallons per acre.

May, 1914

Gallons treated	Gallons pumped	Wash water	Gallons filtered	% Wash water
123,541,000	108,876,000	10,776,000	119,652,000	9.0

Filters washed	Ave. minutes wash water	Alum Pounds	Alum Grs. gal.	Ave. filter hrs. per day	Ave. No. filters service
222	8.4	44,344	2.5	77.0	3.2

Ave. length run between washings	Ave. percent of time filters in service	
10.7 hrs.	53.6	Rate of all filters 104.4 million gallons per acre.

The new water works complete, as described above, cost, ready for service, exclusive of Brazos Brook reservoir, a total of $280,000.00. Plate No. III gives general plan, elevation and section of the plant—see also Figures 5 and 6.

PERMANENT WATER SUPPLY FOR THE SOUTHERN END OF THE PANAMA CANAL.

Early in 1913 it was realized that the growth of the city of Panama; the concentration of the greater part of the operating forces of the Canal at Balboa and vicinity; the construc-

Fig. 5. Mount Hope Purification Plant. Cristobal and Colon Water System.

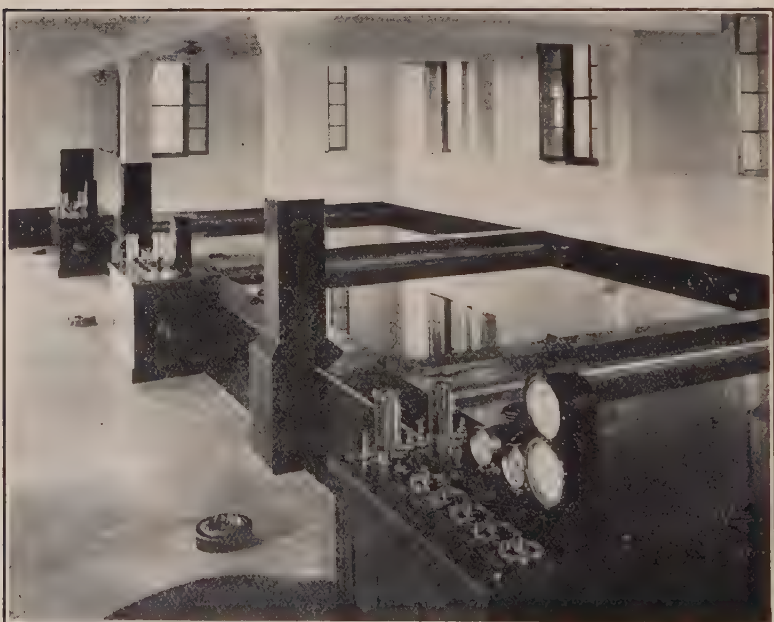


Fig. 6. Mount Hope Filtration Plant. Partial Interior View Showing Filters.

tion and operation of the great shops and terminals at the Pacific entrance to the Canal; and the great increase in shipping making Balboa a port of call, not to except vessels passing through the Canal, made necessary the abandonment of the original water supply and water works as inadequate and unsuited to meet the demands that would result from this growth and expansion. Accordingly, the writer was authorized, after several projects had been considered, to take charge of the design and construction of the system now building and described herein.

The project, as first recommended and adopted, involved the taking of the raw water from one of the eastern arms of the newly created Miraflores lake and pumping it to a purification plant, to be located on the crest of the ridge at the eastern end of the Miraflores spillway, at elevation 116 feet (35.36 meters) above sea-level; the laying of a new 30-inch (762 mm) diameter cast-iron main from this plant to a pumping station to be located at Ancon, midway between Panama city and the Canal terminals; the connecting of this new main with the existing 16-in. and 20-in. (406.4 mm and 508 mm) mains, to give three mains in all between Miraflores and Ancon; the installation of low- and high-service pumps in the new Ancon pumping station; the construction of a new 1,500,000-gallon (5,678,100 litres) capacity reservoir on the side of Ancon hill, at elevation 300 feet (91.44 meters) above sea-level—this structure to be built as an extension of the existing 1,000,000-gallon (3,785,440 litres) reservoir, thus giving 2,500,000 gallons (9,462,500 litres) high-service storage; and the installation of new 20-inch and 16-inch (508 mm and 406 mm) mains throughout the district at the southern end of the Canal.

The decision to adopt the Miraflores Lake as a source of supply was based on the fact that thereby a saving of nearly $500,000 could be effected in the total cost of the whole project, over any other project considered practicable or desirable.

The average elevation of the floor of the Miraflores Lake at the upper end of the Miraflores locks is 15 feet (4.57 meters) above mean sea-level. The elevation of the upper sill of the locks is 11 ft. (3.35 meters) above the same datum and the ship channel in the lake was dredged to this latter elevation.

It was recognized that the chlorine content of the lake water would rise following the opening of the locks to traffic, and that the water in the vicinity of the locks themselves would eventually reach a more or less high degree of salinity. The question as to what extent this increase in salinity at the locks would affect the surface water at the intakes to the water-supply pumps, located in a remote arm of the lake and where three large creeks empty into same, was considered a debatable one, and it was decided to chance this water remaining sufficiently low in chlorine until actual results proved otherwise. This decision involved the accomplishment of certain work on the raw-water pump station, lying below water-level, before the lake was filled. In the event of the water becoming unfit for use, this work would be lost; while, on the contrary, if the water remained sufficiently low in chlorine, a decision to abandon Miraflores Lake at this early date would result in an unnecessary expenditure of nearly a half million dollars.

During the time between the flooding of the Miraflores basin and the completion of the new water-supply system, temporary pumps, located near the proposed permanent station, are pumping the water to all parts south of Miraflores for domestic and industrial uses. The water is given a treatment of hypochlorite of lime, in amounts up to eight-tenths part per million available chlorine, with good results.

The placing of the locks in operation in November, 1913, was immediately followed by a rise in chlorine in the lake, and by February, 1914, this content had risen to 100 parts per million on the bottom and 50 parts on the surface. Observations and certain experiments during this period seemed to point conclusively to a constantly progressive diffusion taking place throughout all areas of the lake. Based on a theory of ultimate complete diffusion of a lock chamber of water for each vessel entering the lake with the entire volume of the lake, and considering also the run in of fresh water from the water-shed, a probable average ultimate chlorine content may be predicted for any given number of lockages per year, combined with any given input of fresh water to the lake during the same period.

By May, 1914, the chlorine had risen to 150 parts per million on the bottom and from 50 to 100 parts on the surface

throughout the lake. It was then decided definitely to abandon Miraflores Lake as a source of supply and to move to the Chagres River at Gamboa, or, more strictly, to an arm of the Gatun Lake at this point.

The same theories as to the rise in chlorine in the Miraflores Lake may be expected to apply to the Gatun Lake as well. But computations based on such a theory indicate that the water of Gatun Lake at Gamboa may not rise appreciably in chlorine content, influenced as it will be by the great volume of fresh water constantly pouring through what may be considered, at Gamboa, a narrow neck of the lake. In the event, however, of such a remote contingency arising, resulting, in the distant future, in the water becoming too high in chlorine for use, the pump station at this point would become a relay station on a main laid to Alhajuela, where the water supply could be taken directly from the Chagres River at elevation 90 feet (27.43 meters) above sea-level.

The project now being rushed to completion provides for a maximum supply of 15,000,000 gallons (56,781,000 litres) per 24 hours, taken from the Gatun Lake and pumped to the purification plant at Miraflores, referred to above, through a single cast-iron bell and spigot main, varying in diameter from 24 inches to 36 inches (609.6 mm to 914.4 mm), laid along the roadbed of the Panama railroad.

The summit along the railroad reaches an elevation of 271 feet (82.6 meters) above sea-level, distant from Gamboa 17.300 feet (5.27 km.). From this point to the purification plant at Miraflores, a distance of 43,700 feet (13.32 km.), the water will flow by gravity.

The water at Gamboa will be drawn from the surface into a gate house, and upon entering will pass through double screens. It will then pass through a 30-inch (762 mm) culvert to the sump below the floor of the pump station.

The pumping equipment will consist of one 2000-gallon (7570 litres) and three 4000-gallon (15,142 litres) per minute capacity centrifugal pumps. These pumps will be direct connected to induction motors, operating on 2200-volt, 3-phase, 25-cycle current, and designed to deliver the above amounts of water to the summit, at elevation 271 feet (82.6 meters) above

sea-level, from a low-water level in the lake of 79 feet (24.08 meters) above sea-level.

Space does not permit taking up the details of the 24-inch, 30-inch and 36-inch (609.6, 762 and 914.4 mm) lines, but it may be of interest to state that leadite will be used almost exclusively in laying this line. To date, approximately 20,000 lineal feet (6.09 km.) of 30-inch (762 mm) cast-iron main, 60,000 feet (18.29 km.) of 20-inch (508 mm) main, and 10,000 feet (3.05 km.) of 16-inch (406 mm) main have been laid and placed in service on the Isthmus, using leadite in place of lead at a large saving in cost.

The purification plant, located at Miraflores, as stated, has been designed along the same general lines as the plant at Mount Hope, and for a maximum total output of 15,000,000 gallons (56,781,000 litres) per day.

The plant is laid out on one longitudinal center line (See Plate IV) and the buildings cover a ground space approximately 130 feet (39.6 meters) in width by 650 feet (198.1 meters) in length.

The aeration basin is 86 x 130 feet (26.2 x 39.6 meters) in plan. The head-house is a three-story structure, 38 ft. 6 in. x 92 ft. (11.75 x 28 meters) in plan. The sedimentation basin is 125 x 300 feet (38.1 x 91.44 meters) over-all and 16 ft. 6 in. (5.03 meters) in depth. The laboratory office and quarters building, three stories in height and forming the end of the filter building proper, is 29 ft. x 51 ft. 6 in. (8.8 x 15.7 meters) over-all. The filter building covers a space of 62 x 147 feet (18.9 x 44.8 meters).

The water reaching the aeration basin is thrown about 15 to 20 feet (4.6 to 6.1 meters) in the air through specially designed nozzles. It passes over measuring weirs placed on the floor of this basin, and thence through the walls of the head house into the mixing chambers on its way to the sedimentation basin.

The head house has the mixing chamber located on the basement floor. The second floor carries the alum-control and Venturi-meter apparatuses, also hydraulic control apparatus, for draining the sedimentation basin and for operating the inlet valves to the aeration basin, and miscellaneous electric indica-

tors. The third floor provides storage for alum and hypochlorite of lime. This floor also carries the four suspended solution tanks for these chemicals.

The sedimentation basin, to be operated on the continuous plan, provides for 8 hours' sedimentation. There are many details for filling, cross filling, emptying and baffling, which, so far as the writer is aware, are not usually embodied in basins of this character, which might be of interest but cannot be dwelt upon in this paper for lack of space.

The filter building proper contains 14 filter units 19 ft. 9 in. x 21 ft. 6 in. (6.02 x 6.56 meters) in plan by 11 ft. (3.35 meters) in depth, ranged seven on each side of a central gallery. These units are built over a clear-water basin having a capacity of 900,000 gallons (3,406,896 litres).

The operating floor is placed 2 ft. 6 in. (762 mm) below the tops of the filter walls and forms a gallery extending the length of the building from the main floor of the office and laboratory building. The filter area is covered by a tile and concrete roof carried on arched steel trusses of 61 ft. 6 in. (18.75 meters) span.

These filters differ from the other filters described, in their under drainage and collector system. The so-called false bottom principle has been adopted, and the design has been based on full-sized experiments under nearly operating conditions.

Each entire filter is built of reinforced concrete throughout. The false floor and main floor, two feet below (610 mm), are designed for 30 pounds per square inch (2.1 kg. per sq. cm.) pressure. The upper or false floor, on which is carried the sand and gravel, is pierced with ⅜-inch (9.5 mm) diameter brass pipes extending above the top side and turning 180 degrees so as to discharge downward. On each of these pipes may be screwed a specially designed brass strainer carrying twenty-five 1/16-inch (1.6 mm) diameter holes. These pipes are placed on 6-inch (152.4 mm) centers and give a ratio of 475 to 1 between area of filter surface and area of openings. The strainer system has been designed for 15 gallons of wash water per square foot (611 litres per square meter) of area of filtering surface. Experiments indicate that this will require 16 pounds per square inch (1.12 kg. per sq. cm.) pressure under the false bottom.

A separate air system has also been provided, to be placed about 4 inches (101.6 mm) below the top of the gravel bed.

The gravel bed will consist of three layers of graded sizes of gravel. At the bottom will be placed ten inches (254 mm) of gravel having a mean size from 1 in. to 1¾ in. (25.4 to 44.4 mm); next above this will be placed 8 inches (203 mm) of gravel with a mean size from 1 to 7/16 inch (25.4 to 11.2 mm) and on top of this will be placed 6 inches of gravel (12.7 mm) of a

Fig. 7. Water Purification Plant at Miraflores.

size from 7/16 to 3/16 inch (11.2 to 4.76 mm). The sand bed will be 30 inches (762 mm) in depth and the sand will run about 0.4 mm with uniformity coefficient of 1.6. The same trough system will be installed as put into the Mount Hope plant.

The filters will be run either with or without negative head, and will discharge their effluent through hydraulic valve controllers directly into the clear-water basin beneath. Hydraulic operation of all valves from slate operating tables will be installed.

The basement of the laboratory and quarters building will contain air receivers, storage rooms, sinks, gas plant and auxiliary laboratory apparatus. On the second or main floor will be placed the office and laboratory, which latter will be fully equipped for all classes of water analysis. The third floor provides quarters for six men.

The water will flow from the clear-water basin through a 30-inch (762 mm) main and Venturi meter to an injection chamber, at which point will be injected hypochlorite bleach or liquid chlorine. The water, upon leaving this chamber, will enter the 16-inch, 20-inch and 30-inch (406, 508 and 762 mm) mains and flow by gravity to the pumping station at Ancon, 4½ miles (7.24 K.) distant. Liquid chlorine equipment will be installed, in addition to the hypochlorite apparatus, with a view to operating with the hypochlorite in reserve.

Fig. 8. Main Operating Floor, Miraflores Water Purification Plant.

The wash water will be pumped, by means of centrifugal pumps located in pump station No. 2 (see plate No. IV), into a 300,000-gallon (1,135,632 litres) wash-water tank, located on

the hill above the purification plant at elevation 191 feet (58.21 meters) above sea-level. This tank will provide filtered water by gravity to the town of Pedro Miguel to the north, and, in addition to the wash water, will provide the service water around the plant.

Pump station No. 2 will contain three 2500-gallon (9463 litres) per minute centrifugal pumps, motor driven, and one 500 cu. ft. (14.16 cubic meters) per minute air compressor. This station will be located in relation to the main plant as shown on Plate IV.

The Ancon pumping station (pump station No. 3) will contain two high- and three low-service pumps. The water from Miraflores will, under conditions of maximum flow, reach this station at practically zero head. The low-service pumps will act as boosters and pump directly into the 20-inch (508 mm) cast-iron discharge main running east to Panama City and west to the Canal terminals. All connections, at elevation 60 feet (18.3 meters) above sea-level, will be placed on this system and the service pressure will not exceed 50 pounds per square inch (3.5 kg. per sq. cm.).

On this 20-inch (508 mm) main will be tied the 1,000,000-gallon (3,785,440 litres) reservoir, located at elevation 137 feet (41.75 meters) above sea-level; referred to on page 11, and it will be used as a surge tank or reserve to take fluctuations in supply and consumption.

The two high-service pumps will act as boosters pumping the water through a 16-inch (406 mm) discharge main into the high-service system and into the 2,500,000-gallon (9,462,500 litres), reservoir located at elevation 300 feet (91.4 meters), referred to on page 25. All connections above elevation 60 feet (18.28 meters) will be supplied off this system. The reservoir will be operated in the same way as the low-service reservoir.

The piping is so arranged in the station that the high-service, in case of fire, can be thrown into the low-service system to the east or to the west of the station, or both, depending on the location of the fire. This operation will be controlled by hydraulic cylinder valves operated from a central slate operating table placed on the station floor. The change from low to high service will be a matter of not to exceed 30 seconds.

The low-service pumps will be single-stage, centrifugal pumps direct connected to induction motors, 5000 gallons (18,927 litres) per minute capacity against 125 ft. head (38.1 meters). The high-service pumps will be 3-stage pumps of similar design, with capacity of 2500 gallons (9463 litres) per minute each against 350 feet (106.7 meters) head. Motors will operate at 2200 volts on a 3-phase, 25-cycle current.

The entire project as described above is estimated to cost $1,250,000 and will be ready for operation by April 1, 1915.

Upon the completion of this project, there will have been expended for permanent water-supply plants on the Isthmus approximately $2,000,000. In addition to this amount, there has been expended for temporary water supplies and water systems throughout the Canal Zone, since the beginning of American occupation, approximately $4,892,309.53.

The average cost of filtration at the new Mount Hope plant is $0.0139 per thousand gallons (3785 litres). The average cost at the Agua Clara plan is $0.0176 per thousand gallons (3785 litres). It is estimated that average cost of water delivered to the consumer per thousand gallons, based on averages of all plants and all conditions of head pumped against, including pipe lines and all fixed charges, will amount to 10 cents.

The total expenditures for municipal work of all kinds from June, 1904, to date of completion of this last water project, including the work in the cities of Colon and Panama, will amount to approximately $12,652,048.94. Of this amount, the Republic of Panama pays back within 50 years to the U. S. Government approximately $3,288,483.78.

Paper No. 7

THE WORKING FORCE OF THE PANAMA CANAL.

By

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Labor and material are the two fundamentals of any large construction job. With no market near at hand for either, both were problems in the early stages of the Canal work, and of the two, in fact of all the problems confronting the builders of the Canal at its beginning, the labor problem seemed the most difficult and the one hardest to solve. It was really not until 1908, or more than three years after the beginning of the work that it could be considered entirely solved.

The working force of the Canal was divided into what are known locally as the "Gold" and "Silver" forces, so termed because originally some of the force were paid in U. S. currency and the balance in Panamanian currency. Later on all were paid alike in U. S. currency, but the term always obtained. The "Gold" force consisted of the officials, superintendents, foremen, the clerical force, and the higher grades of skilled labor; in general all American citizens on the work. The "Silver" force consisted of the unskilled labor and the lower grades of skilled labor; in general all the West Indians and European labor on the job. The "Gold" force had a higher wage scale and more privileges than the "Silver" force. Roughly, the "Gold" force may be compared to the officers and non-commissioned officers of an army—the "Silver" force to the privates in its ranks.

The table below shows the maximum effective force during each year of construction work. These figures include the Panama Railroad force, but do not include the forces of the contractors. The latter secured much of their skilled labor and

practically all of their unskilled labor from the men recruited by the United States Government; however, with the exception of the lock gate contractors, no appreciable force was ever maintained by contractors on the Isthmus. At one time the McClintic-Marshall Company, who had the contract for the lock gates, had over 5000 men at work, and if their force is taken into consideration the maximum effective force was reached on March 26, 1913, when the total number of men actually working was 44,733. The force shown in the table below includes only men actually at work and does not take into consideration men temporarily laid off, the sick, those on leave and other absentees. If these are considered at least 20% should be added to give the total number on the rolls for any given period.

Maximum Force Employed During Each Year of Construction Work.

May, 1904	1,000	(Approximately)
Nov., 1904	3,500	"
Nov., 1905	17,000	"
Dec., 1906	23,901	
Oct., 1907	31,967	
Apr., 1908	33,170	
Oct., 1909	35,495	
Mch., 1910	38,676	
Dec., 1911	37,826	
June, 1912	38,174	
Aug., 1913	39,962	
June, 1914	33,270	

It will be noted that the force increased from 1000 in 1904 to over 30,000 in 1907. Considering conditions, the recruiting and organization of a force of over 30,000 men in less than three years was a great task.

When the American authorities took over the work from the French Company in 1904, they found a small force of West Indian laborers with a few French officials and engineers in charge—not over 1000 men in all. There was no surplus labor on the Isthmus or in the entire Republic of Panama, the population being comparatively sparse. It was early realized that it would be necessary to recruit all classes of labor in other markets. It was not, however, realized on just how large a scale this

would have to be done, for no one foresaw the proportions of the work, its widely varied character and the resulting large supply of labor required.

The steps taken to recruit the working force are described in detail below.

In building the Canal the United States Government not only undertook a great construction work, but it handled all auxiliaries that are frequently delegated or sub-let. It conducted the Government of the Canal Zone, created a fire department, police department, department of schools, operated hospitals, commissaries and hotels, operated the Panama Railroad, in fact, handled practically all work directly or indirectly connected with the construction. It was therefore necessary to obtain not only transportation and excavation men, but firemen, policemen, cooks, stewards, nurses, doctors and many other classes of labor, using labor in its broadest sense.

It was recognized that most of the superintendents, foremen, and the higher grades of skilled labor would have to be brought from the United States. There was no surplus throughout Central or South America, and in many classes of the work there were no men at all available in the Central or South American field. It was known that to secure good men would be a difficult task on account of the climate and reputation of the Isthmus. Panama had been widely advertised as a pest hole during the French period, and the yellow fever epidemic which occurred in the early days of American occupation—the fall of 1904 and spring of 1905—did not add to its reputation. Mr. J. F. Wallace, the first Chief Engineer, considered the labor problem so all-important that one of the principal reasons for his visit to the States during the spring of 1905 was to secure skilled labor. He made an effort to recruit transportation and construction men and devoted some of his personal attention to the task. For the reasons above mentioned, it was realized that to secure a good class of employees, it would be necessary to offer considerations in the form of high wages. The scale of wages was materially raised during the spring of 1905.

A considerable number of men were brought down in the spring of 1905, but while the pay was attractive, the living conditions were such that a large proportion of those that came, im-

mediately returned. This was the more discouraging as the work was expanding much faster than the force. It was realized that to secure good men it would be necessary not only to offer high wages but good living conditions. When Mr. Stevens came to the Isthmus in July, 1905, he gave preferred attention to the building of quarters on a very large scale, the organization of commissaries, the recreation of employees, and to all other matters connected with the improvement of living conditions on the Isthmus.

Mr. Stevens considered the labor problem, for the time being, as the most important problem of the work. He brought with him Mr. Jackson Smith, a man who had been connected with construction work in Jamaica, Ecuador and Mexico, and of wide experience in the recruiting and handling of labor in the tropics. Mr. Smith at once created an organization for the recruiting of skilled and unskilled labor. To obtain the former he appointed four agents in the United States, one located in New York, one in New Orleans and two with roving commissions to recruit and dispatch men from the States to the Canal Zone. These men worked in conjunction with the Washington office of the Commission.

Originally the Civil Service rules had been applied to practically all classes of employees on the work. With the exception of the clerical force, the doctors, nurses and draftsmen, the Civil Service was disregarded and men were employed direct by the agents appointed by Mr. Smith.

The recruiting agents made personal inquiries as to the antecedents of, and the class of work performed by, every applicant for employment. All had to undergo a medical examination and every precaution was taken to insure recruiting good men. Nevertheless, the class of men first secured was rather discouraging. Most of them were men who, for one reason or another, were unable to retain positions in the States, and were equally unable to give good results on the Isthmus. The reputation of the Isthmus deterred the best class of applicants, but by degrees the high wages, fair treatment and good living conditions had their influence, and American construction men as early as 1906 began coming of their own accord to the Isthmus. The following table shows the number of "Gold" employees re-

cruited in the United States during the different years of Canal construction:

December	1905-1906	3,243
	1907	3,038
	1908	1,828
	1909	754
	1910	1,099
	1911	1,083
	1912	632
	1913	1,183
	1914	1,429

This table does not include Americans hired on the Isthmus. The proportion of such employees, though small at first, increased rapidly until in 1908 there were more men hired on the Isthmus than there were recruited and sent down from the United States. From 1908 to the end of the work this same condition obtained, as there were plenty of men who were drawn to the Isthmus from the reports of others who were working on the Canal and who advertised the job. After 1908 the number of applicants was so great that it was no longer necessary to maintain any recruiting officers in the field. The recruiting organization in the States was dissolved, with the exception of the New York office. After 1911 this office was abolished and all employments were made through the Washington office of the Commission.

The average number of Americans working for the Canal during the construction period was a little over 5000. It will be seen from the table of employments that this force had to be renewed every two or three years.

The composition of the "Gold" force was very varied due to the character and size of the work. Speaking roughly, there were three principal classes of employees composing the force. First, the construction men, drawn from the railroads and large contractors of the United States. Second, the construction men drawn from the tropics; Mexico, South and Central America. Third, ex-Government employees who had worked previously for the Government either in the United States or in Cuba, Porto Rico and the Philippines. A large number of the first class, particularly of the engineers and conductors first brought to the

Isthmus, came from the Illinois Central and Rock Island Railroads, the first two chief engineers having been connected with those roads. Later, transportation men came from all portions of the United States, although a small road in the eastern States, the Buffalo, Rochester and Pittsburgh, probably contributed more men than any other single line.

The United Fruit Railroads in Central America, and the Guayaquil & Quito Railroad in Ecuador were built by Americans, and a number of the men who had been engaged in these roads afterwards worked on the Isthmus.

A large number of the clerks and sanitary force had been previously employed in Government departments at Washington, in Cuba, Porto Rico and the Philippines, while a number of the dredge men had worked on Government work on the Mississippi River.

UNSKILLED LABOR.

When the first French company failed in the late 80's, there were approximately 20,000 West Indian laborers left stranded on the Isthmus. These laborers had no money to pay their passage home; there was no possibility of employment on the Isthmus of Panama and much suffering and hardship resulted. The Island Governments of the West Indies, none of whom had any surplus funds, had to repatriate their countrymen at Government expense. When the work on the Canal was resumed by the Americans, the whole project was looked on with suspicion throughout the West Indies, both by the laborers themselves and by the authorities.

Mr. Jackson Smith created a recruiting organization for unskilled labor as well as skilled labor. One agent had already been sent to Barbados by Mr. Wallace. Mr. Smith sent others to the French West Indian Islands, to the Republic of Colombia, and later on to Cuba.

The situation confronting these labor agents was a difficult one. The British West Indies were the natural markets of the Canal for unskilled labor, but they were at first closed to the Canal agents. This was due to two causes: First, suspicion on the part of the authorities and of the laborers as to the treatment they would receive from the Canal authorities. Second, opposi-

tion of the planter element in the islands, who desired to maintain a surplus of labor and who threw every possible obstacle in the way of immigration from the Islands. It did not take long to remove the first objection—the second one always remained in force. The policy was really short sighted, as in the end the immigration to the Isthmus proved a benefit to the Islands; the West Indian laborer saved his money and sent large sums home, much as the Italian immigrant does from the United States. These remittances proved a decided factor in the betterment of conditions in many of the smaller West Indian Islands.

It has been frequently stated that the Canal was built by Jamaican labor. This is an error. The Island of Jamaica, which is the largest and most populous of the British West Indies, was the nearest island to the Canal and the natural recruiting ground for unskilled labor. The authorities in this island, throughout the construction period, consistently refused to allow any recruiting to be done. A tax of one pound Sterling per man was imposed on any man desiring to leave the island for the Isthmus. To pay this tax and to pay the passage was beyond the reach of the average unskilled laborer, whose wages did not exceed 30c. per diem. There was, however, a large immigration from Jamaica to the Isthmus, but it was composed mostly of negro artisans, and not of ''pick and shovel'' laborers.

For some time the recruiting agents made little headway, but the authorities in the Island of Barbados finally gave a free hand to the Commission and shipments began on a large scale. Conditions in this Island were unique. With an area of less than 200 square miles, it had a population of almost 200,000 negroes. As there was no industrial life and no large cities, the people lived off the land, and the struggle for existence was real in every sense of the term. The surplus of labor was so great that the planters withdrew their opposition and shipments began in the summer of 1905. From first to last, 19,900 men were recruited in Barbados, approximately 10% of the total population and from 30 to 40% of the adult males.

The authorities in the French Islands of Martinique and Guadaloupe finally permitted recruiting to be done under certain restrictions, and although the permission given was withdrawn in 1907, 7,500 men were recruited in these Islands. The

French negro, while a willing worker, as a rule had not the physique of the Barbados negro and was handicapped by his lack of knowledge of English. All West Indians were recruited under contract, under which their transportation was paid to the Isthmus, and under which they were given the privilege of repatriation after a period of 500 working days. West Indian laborers were given 10c per hour for pick and shovel work, were furnished free quarters and medical attendance, and allowed commissary privileges. As a matter of fact, the wages of most West Indian laborers averaged considerably more. It was only during the first part of their service that they received the 10c rate.

The agents had difficulties in obtaining recruits to make up the first few shipments, but the news of the high wages and good living conditions on the Isthmus soon spread throughout the West Indies and later on the supply much exceeded the demand, particularly after the first three years of Canal work.

During 1905 and 1906 the work expanded so rapidly that in spite of the large shipments of labor—approximately 20,000 men during the two years—the requirements exceeded the supply. However, the efficiency of the West Indian laborer was very low, and it was decided to introduce another class of unskilled labor on the work. An agent was sent to Cuba early in 1907, and a trial shipment of about 400 Spanish laborers was sent to the Canal. These Spaniards rendered such satisfactory service that Mr. Leroy Parke, the agent referred to, went to Spain and after some preliminary negotiations with the Spanish Government obtained authority to recruit in Spain. During 1906, 1907 and 1908 nearly 12,000 contract laborers were forwarded from Europe, of which approximately 75% were Spaniards and the balance Italians and Greeks. The European laborer was paid twice as much as the West Indian laborer for exactly the same class of work, but his efficiency at first was rated as approximately 3 to 1 as compared to the negro. The presence of this European labor had a great effect on the West Indian and the efficiency of the latter was increased by competition, while after a time the efficiency of the European laborer diminished from the effects of the climate. At the end of the construction period there was no great difference between the two classes of labor.

The conditions of the contract under which the Spanish laborer was recruited differed somewhat from the contract entered into with the West Indian laborer. The passage of the European laborer was paid to the Isthmus, but the cost of his passage was afterwards refunded to the Commission out of the laborer's pay. There was no guarantee to repatriate European laborers, although a large number of them were eventually sent home at the expense of the Commission.

The table on page 10 shows the contract laborers brought to the Isthmus throughout the work.

As shown by the table, the maximum movement of contract labor occurred during 1907 when nearly 15,000 men were brought to the Isthmus. About this time a large unaided immigration set in, both from the West Indies and from Europe, the excess of immigrants over emigrants being shown below:

1908	Excess of immigrants	18,000
1909	" " "	13,023
1910	" " "	21,114
1911	" " "	4,910
1912	" " "	3,510
1913	" " "	9,534

This tide of immigration soon relieved the Commission of the necessity of maintaining a recruiting organization, and all agents were relieved by the end of the year 1909. A few small shipments were afterwards sent forward, but the number of men recruited was very small after 1909.

The great bulk of unskilled labor secured was originally agricultural labor. Practically all of the West Indians had worked in the fields and had never done any construction work. Many of them had never seen a railroad; few of them were acquainted with explosives. Outside of the building trades, none of them were of any value as artisans. All were slow and stupid, and altogether they were most unpromising material. The Europeans were as a rule much more intelligent, but few of them had ever worked on a construction job before. They stuck more steadily to the work than the West Indians and were, in the beginning at least, much more to be depended upon. The West Indian, in addition to his other defects, could not be relied upon

Country	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	Total
Spain	......	......	1,174	5,293	1,831	......	......	......	......	......	8,298
Cuba	......	......	500	......	......	......	......	......	......	......	500
Italy	......	......	909	1,032	......	......	......	......	......	......	1,941
Greece	......	......	......	1,101	......	......	......	......	......	......	1,101
France	......	......	19	......	......	......	......	......	......	......	19
Armenia	......	......	14	......	......	......	......	......	......	......	14
Total Europeans	......	......	2,616	7,426	1,831	......	......	......	......	......	11,873
Fortune Island	......	......	361	......	......	......	......	......	......	......	361
Barbados	404	3,019	6,510	3,242	2,592	3,605	......	......	......	528	19,900
Guadeloupe	......	......	......	2,039	......	......	......	......	14	......	2,053
Martinique	......	2,733	585	2,224	......	......	......	......	......	......	5,542
Jamaica	......	47	......	......	......	......	......	......	......	......	47
Trinidad	......	......	1,079	......	......	......	205	......	143	......	1,427
Curacao	......	......	23	......	......	......	......	......	......	......	23
St. Kitts	......	......	933	......	......	......	......	......	9	......	942
St. Lucia	......	......	......	......	......	......	......	......	55	......	55
St. Vincent	......	......	......	......	......	......	......	......	296	......	296
Grenada	......	......	......	......	......	......	......	......	93	......	93
British Guiana	......	......	......	......	......	......	......	......	332	......	332
Total West Indies	404	5,799	9,491	7,505	2,592	3,605	205	......	942	528	31,071
Costa Rica	......	244	......	......	......	......	......	......	......	......	244
Colombia	......	1,077	416	......	......	......	......	......	......	......	1,493
Panama	......	334	10	13	......	......	......	......	......	......	357
Not classified	......	......	69	......	......	......	......	......	......	......	69
Grand Total	404	7,454	12,602	14,944	4,423	3,605	205	......	942	528	45,107

in the beginning to work steadily. It is doubtful whether at first many of them averaged more than 15 working days per month.

The evolution of the unskilled laborer has been as marked as the evolution of the work. The West Indian, while slow, has learned many of the trades and many of them have developed into first class construction men. The bulk of the building work on the Canal has been done by West Indian carpenters, masons and painters, under the direction of American foremen. The drilling in the cut and the firing of locomotives were all done by West Indians. Particularly in the trades mentioned the men developed steadiness, and toward the end of the construction period the West Indian remained on the job as steadily as the Spaniard or even the American. While not comparable with the efficiency of unskilled labor in the United States, there was nevertheless tremendous improvement, and this improvement is the best kind of a tribute to the American foremen who developed and educated this labor.

After 1909 no agents were maintained in the West Indies by the Canal authorities. The withdrawal of the agents was the result of the growing stability of the force. While the figures of contract laborers recruited and of Americans employed in the United States and the Isthmus of Panama apparently show a rapid change in the personnel of the force, it was not due, except in the small minority of cases, to the conditions on the Canal. The Isthmus, in turn, was used as a recruiting ground by every large construction enterprise throughout Central and South America. The Madeira & Mamoré Railway, constructed by Americans in Brazil, was largely manned, from its Chief Engineer down to its unskilled labor, by ex-Canal employees. Americans, Spaniards and West Indians on the Canal work were drawn on for enterprises in Chile, Peru, Ecuador and Central America. This was largely prevented after 1908 by the passage of a law by the Panamanian Government forbidding the recruiting of labor on the Isthmus. The force within the last six years of the construction period was, considering the conditions, a very stable one, and this was due to the fact that the men brought to the Isthmus were, in the main, contented with their surroundings. The steps taken to insure an efficient and contented force are described as follows:

QUARTERS.

When the French company turned over the Canal to the Americans, there were 2148 houses belonging to the company in various settlements along the Isthmus. All of them were old and almost all of them were in a very dilapidated condition. Up to the end of 1905, the quarters were not only insufficient in quantity but were of such a character that the employees were very discontented. Mr. Stevens recognized this fact, and immediately after his arrival organized a building department with a very large force, which set to work to provide quarters on a large scale for present and future forces.

The building construction was all frame. A large number of so-called tropical flats or frame four-family apartment houses were put up to accommodate American families. Besides these, cottages and somewhat more pretentious houses were erected for the higher salaried employees and officials. All houses erected were screened, modern plumbing installed and conveniences heretofore unknown in the tropics supplied. The houses were furnished without rent by the Isthmian Canal Commission. The furniture was supplied free, also water, fuel and light. Two types of houses, the first accommodating 24 and the second 48 men, were erected for bachelor employees.

While the accommodations furnished to married Americans were much more expensive than those furnished bachelors, it was realized that to keep a stable and contented force on a job that would take from five to ten years to complete, it would be necessary to allow a certain proportion of the men to bring their families to the Isthmus. At one time almost 2000 American families were in Commission quarters on the Isthmus, or 40% of the "Gold" force.

A large number of barracks for the laborers were erected and equipped with Standee bunks or cots. Outside closets, bath houses and wash houses were provided in the colored camps adjacent to the barracks.

To properly equip, care for and assign the quarters was in itself a considerable task, and a department was formed, originally known as the Department of Labor, Quarters & Subsistence, later known as the Quartermaster's Department, which was

charged not only with the recruiting of labor but with the assignment and care of quarters for skilled and unskilled labor after it arrived on the Isthmus. Janitors were provided for the American bachelor employees, and also for the barracks for the colored and European laborers. All such quarters were kept in a clean, sanitary condition. The married employees were obliged to care for their own houses, but the grounds were policed, garbage removed and commissary deliveries made by the forces of the Quartermaster's Department.

FOOD.

There were no adequate facilities for feeding the force when first organized. Very little produce of any kind was raised on the Isthmus, and there were but few stores, those in existence charging very exorbitant prices. Under these conditions, to feed 50,000 employees and their dependents was in itself a tremendous task, and the solution of the problem was one of the greatest features toward getting a healthy and contented force. An ice and cold storage plant, bakery, laundry, and wholesale warehouse were erected at Cristobal, the Atlantic terminus of the Canal. Ample refrigerating facilities were provided in Panama Railroad steamers and a number of refrigerating cars provided by the Panama Railroad. Commissaries were established at every settlement along the Isthmus where work was being carried on. A supply train carrying the ice and cold storage supplies to all employees on the Isthmus was sent out daily from Cristobal and supplies delivered to the line commissaries and families. These commissaries were really small department stores carrying all the necessaries of life and some of the luxuries. Their business developed to huge proportions, the sales at one time averaging over half a million dollars per month. They were self-sustaining, but, on account of the volume of the business transacted, prices were very reasonable. After 1908 it was possible for the wage earner on the Canal to obtain the necessities of life at prices lower than he would pay in retail stores in most parts of the United States.

Hotels or restaurants were erected for the American bachelors. These restaurants furnished 30c meals. A number of mess halls were put up for the European laborers where meals were

furnished at 40c per diem. Kitchens were erected for the West Indian laborers and rations furnished and cooked in these kitchens for 30c per diem. Every possible effort was made to insure comfortable living quarters and proper food, and although, on account of lack of facilities, it was an up-hill task in the beginning, the problem was worked out, and no large body of men ever lived under such favorable conditions as the employees of the Canal during the construction period.

HEALTH.

The work of the Sanitary Department has been so often described that it is unnecessary to discuss it in this paper. It is sufficient to state that the Isthmus of Panama, once a pest hole, has been made healthy, and the sick and death rate among employees reduced to a minimum. This was accomplished by a strict quarantine, effective sanitary measures, and a modern and up-to-date system of hospitals. Strict quarantine prevented disease being brought to the Isthmus from the plague and fever infected ports of Central and South America. An efficient sanitary division adopted every preventive method possible, eliminated the yellow fever bearing mosquito and largely reduced the malaria spreading mosquito. Dispensaries with capable doctors were located at every point along the Isthmus, and two large base hospitals established in Ancon and Colon, where the best medical attendance was given to sick employees.

Medical attendance was furnished free to every employee and to every member of his family.

COMPENSATION ACT.

On account of the magnitude of the work and dangerous character of much of the construction, there were a great number of unavoidable accidents, particularly during the early period of the work. The West Indian and European laborers were originally entirely ignorant of the dangerous character of explosives, and many accidents resulted. The compensation act was finally passed, which protected not only the Americans, but also the West Indian and European laborers, in case of injury or death from results of accidents on the work.

LEAVE PRIVILEGES.

Liberal leave privileges were granted throughout the construction of the Canal. Six weeks leave with pay was given each year to every American employee on the monthly roll, and reduced rate granted on Government boats between New York and Colon. In addition, thirty days sick leave, with pay, was allowed to every American employee, and in the event of an employee being incapacitated by injury occurring in performance of his duty, an additional thirty days leave, with pay, was granted.

MISCELLANEOUS.

Public schools were maintained for American children, also for the native and West Indian children. Buildings were provided for religious purposes and chaplains representing the various denominations were carried on the rolls of the Commission. Six Y. M. C. A. buildings were constructed free of cost by the Commission, which also contributed a portion of their operating expenses. Suitable meeting places were provided for fraternal orders and lodges. Every assistance was given to legitimate organizations for promoting recreation for the employees.

Complaints: Col. Goethals, at the head of the work, gave free access to every employee desiring to lodge a complaint. A painstaking investigation was made of every case. Every just complaint received redress, and the evils inherent in any bureaucracy were minimized.

CONCLUSION.

When the size and character of the work and composition of the force are considered,—a force drawn from such widely scattered sources and with such diverse aims and objects,—it must be admitted that to weld it together and inspire it with an enthusiastic *esprit de corps* was one of the greatest triumphs of the work. The Canal will always remain a material monument from a construction and engineering standpoint; it will also stand as a monument in the minds and hearts of the employees who worked on it during the construction period—a monument no less enduring than its physical presence. Every wage earner,

whether a high salaried superintendent or division head, or the lowest paid West Indian laborer, was given a chance in every sense of the term, and was able to earn more than his living expenses. The handling of the working force during the construction of the Canal will always stand as a model of an intelligent, just and liberal treatment of labor.

Paper No. 8

PURCHASE OF SUPPLIES FOR THE PANAMA CANAL.

By

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Purchasing for the Government is so bound around by rules, regulations and restrictions, in common parlance "red tape", that to the average layman "Government Purchase" is synonymous with unbusinesslike methods and extravagance. Instead of attributing these rules to the proper source, the individual official is frequently held responsible, and his refusal to adopt so-called commercial methods of business is claimed to be due to a dictatorial spirit and to a desire to impress with his brief authority. "Red tape" is in fact merely another name for method and system and, while undoubtedly exasperating in certain individual cases, is essential in carrying on a business of any importance. With some of the larger private corporations there is fully as much as with the government, and possibly more.

While this paper is devoted mainly to the methods of purchase used in connection with the construction of the Panama Canal, yet it deals to a certain extent with the larger question of government purchases in general and, it is hoped, will answer some of the criticisms which are leveled at government officials.

CLASSES OF SUPPLIES.

The supplies used at Panama may be divided into two general classes: construction supplies, and subsistence supplies.

The second class includes such articles as eatables, clothing, shoes, toilet necessaries, etc. The first class includes construction material and tools and equipment of all kinds needed

in the actual work on the Canal, or in a few words, all material not included in the second class. The latter caters to the work; the former to the individual workman. With a few exceptions all items of the first class were bought through the purchasing department of the Isthmian Canal Commission in Washington. Those of the second class were handled through a department of the Panama Railroad in New York and are not considered in this discussion.

The system of supply is practically the same now as during the life of the Isthmian Canal Commission. For convenience therefore the official designations formerly in force will be used throughout this paper. The Chairman and Chief Engineer under the Isthmian Canal Commission performed in general such duties as are now vested in the Governor of the Panama Canal Zone.

REQUISITIONS.

The handling of supplies on the Isthmus is, it is understood, to be considered in another paper and it is sufficient here to say that requisitions were submitted in the usual way. Such items as could be supplied from stock were turned over to the division submitting the requisition. Items that could not be so supplied, and items needed to keep up the general stock, were consolidated in requisitions which, after the approval of the Chairman and Chief Engineer, were mailed to the Purchasing Office of the Commission in Washington, D. C. When received in Washington the requisitions were separated, those calling for proprietary articles, or supplies urgently needed, going to the "open market" desk, while those which included articles not urgently needed were sent to the "advertising" desk.

At the "open market" desk items were again divided. To cover proprietary or repair articles, and articles very urgently needed or of small value, letters requesting prices and guaranteed deliveries were sent to the maker specified, or to a manufacturer who had satisfactorily furnished the same supplies previously. For other items similar letters were sent to two or more firms, depending on the urgency, the value and the nature of the article.

At the "advertising" desk the various items were classified and prepared for printed or mimeographed circulars. These circulars gave full information to the bidder, all data relative to general requirements, methods of payment, etc., being inserted on the front page or in the contract form which formed a part of each circular, while the specifications relative to the particular article followed each class. Blank spaces were left for insertion by the bidder of unit and total prices and for the name of the maker of the article and the place of manufacture. The bidder was also requested to insert, in space left therefor, the guaranteed time of delivery at the Isthmus.

ADVERTISING.

Under the law any article whose estimated value was over \$10,000.00 was required, except in emergencies, to be advertised in newspapers, while for articles under \$10,000.00 and over \$1,000.00 it was sufficient to advertise by sending out circular letters or notices, and by posting such notices in a public place. For articles the value of which was under \$1,000 no special legislation had been provided, and they could have been bought without advertising or circular letter if desired. In case of emergency, advertising of any kind could be waived, subject, however, to the approval of the Secretary of War in the case of articles of which the value was in excess of \$10,000.00.

Under the system adopted, however, competition was sought wherever practicable, irrespective of the price, the object being to obtain a satisfactory article at the lowest possible figure. As previously indicated, circular letters were sent to a limited number of such firms as experience indicated were in a position to supply what was needed at reasonable prices. Printed and mimeographed circulars were, however, sent to all firms who were listed in the Washington Office as handling the various articles included. These circulars were also sent to Boards of Trade and Government Offices throughout the country, from Portland, Me., to San Francisco and from the Great Lakes to New Orleans. Information relative to items desired was also printed in the "Government Advertiser" of Washing-

ton, D. C., and advertisements were inserted in various newspapers. In this manner the widest publicity was given.

AWARDS.

The bids on all circulars and practically all circular letters were opened publicly on a certain specified date and hour. Interested bidders were permitted to be present at the opening, at which time bids were read and recorded on an abstract. One copy of all bids was available for reference by representatives of the contractors or others who had a bona fide reason for investigating them. In some cases certain data were made confidential and were not shown to other bidders, as, for example, when a bidder submitted a design which had not yet been patented. These cases were, however, very infrequent.

Information relative to materials needed by the Isthmian Canal Commission was published in the "Government Advertiser" and full data relative to all awards appeared in the same paper. It is thus seen that the public in general has had every opportunity of becoming familiar with the wants of the Panama Canal, and has also been given full opportunity of knowing just what action has been taken.

The Joint Resolution of Congress, Approved June 25, 1906, provided as follows:

> "That purchases of material and equipment for use in the construction of the Panama Canal, shall be restricted to articles of domestic production and manufacture, from the lowest responsible bidder, unless the President shall, in any case, deem the bids or tenders therefor to be extortionate or unreasonable".

The proper interpretation of the above involves the understanding that award should be made to the lowest responsible bidder for the material called for. If the low bidder were known not to be responsible, or had given repeated unsatisfactory service, it has been construed that the law did not compel award to such a bidder. Also if a bidder modifies the specifications, and quotes on some article not called for by the Isthmian Canal Commission, it can hardly be reasoned that Congress intended an award should be made to him.

In handling awards under any particular item, the abstract was consulted and the low bid was referred to. If this low bid was satisfactory in all respects, no further investigation was made, the theory being that certain material was asked for, under certain specifications, and that, except in unusual cases, the government would not be warranted in purchasing at a higher price other material, although the more expensive material might be better than that specified. This theory of course does not hold where the award depends on the samples or specifications to be submitted by the bidder, in which case the Isthmian Canal Commission always reserved the right to make such award as was deemed to the best interests of the government.

The total prices are not always a proper indication of the relative order of the bidders, since in submitting bids one bidder might figure the total weight of a certain article to be greater or less than another bidder. In cases of this kind the unit prices were generally held to govern and award was made accordingly.

Frequently letters were received asking to be advised of awards and requesting information relative to the bids received and prices quoted. It is feared that enquirers have often felt that the Isthmian Canal Commission was withholding information, when they were advised that it was impracticable to answer such letters in detail. However, it can readily be understood that if an answer be made to one, it cannot be refused to another, and if an attempt were made to advise each bidder of all bids received, the additional work would have been of such a large volume that it would have been simply impossible to have added it to the regular routine work, without increasing the force of clerks beyond the limits authorized by Congress. Under these circumstances we were unable to give this information but advised the persons making inquiries that they could find it in full in the "Government Advertiser".

The subject of permitting changes in bids after the same were opened was one which was frequently raised by bidders. The rule adopted was that no change was permitted in any bid and if the prices were reasonable no additional bids were asked for. This rule was maintained rigidly in connection with all items of a bid which might be considered as affecting the price.

For example if the earliest possible delivery was asked for, and the statement was made that early delivery was essential and would be considered in making the award, or if we asked for delivery on a certain date, this delivery was considered an essential part of the bid and no change was permitted after the opening. If on the other hand, no special comment was made relative to the urgency of the delivery, bidders were sometimes permitted to modify their deliveries.

At times this rule seemed to work a hardship on the government, as we were occasionally compelled to accept a higher price, where the low bidder would probably have shortened his time. However, in the long run it is felt that the government benefited, as, if bidders were authorized to change essential items in their bids, there would have been no assurance that their first bids were based on the best price and deliveries, whereas, after the rule became known, bidders were aware of the fact that if they wished to obtain the business, they must submit the lowest possible price and least delivery time in their original tender.

FOREIGN MATERIAL.

It may be of interest to insert here the rule which was adopted under the Isthmian Canal Commission to govern purchase of foreign material.

In interpreting the latter part of the Joint Resolution of Congress quoted above, the final instructions issued by the President under date of March 2, 1909, were as follows:

> "The White House, Washington, March 2, 1909.
>
> To The General Purchasing Officer,
>
> Isthmian Canal Commission.
>
> The following executive instructions in furtherance of Joint Resolution No. 35 of June 25, 1906 (34 Stat. L., 835), will hereafter control in comparing bids for materials to be used in connection with construction of the Isthmian Canal and in determining awards thereon.
>
> When bids which are submitted on materials of foreign production are lower than on material of domestic production and manufacture, preference will be given to

the article of domestic production and manufacture, unless the bid for the latter exceeds the former by an amount equal to the duty on the imported article. Where an article of domestic manufacture is made up, in part, of imported ingredients or components, the presence of such components will be ignored, if the duty has been paid. If, however, the article is manufactured in bond, or if the bid is based on a drawback being paid or allowed, the amount of such duty or drawback should be similarly considered in making the award.

THEODORE ROOSEVELT."

It is noted, however, that this Executive Order was merely a general rule for the guidance of the Purchasing Officer of the Isthmian Canal Commission, and it did not bind the President to accept a bid on foreign material under the conditions laid down, for, if he felt that a bid on domestic material, even though it might be greater than the foreign bid plus the duty, was still not exorbitant, he would, under the Joint Resolution, have been required to direct that the award should go to the domestic concern.

CONTRACTS.

As soon as items were awarded, the formal order was prepared, either in the form of a written contract in cases where the amounts were in excess of $10,000.00, or in the form of an order. These order forms referred to the terms of the specifications and included such additional data as were necessary for the proper supplying and shipping of the material. With each order a set of shipping instructions was enclosed to the contractor, giving him definite information as to how material should be shipped, what papers should be forwarded to various destinations, etc.

INSPECTIONS.

One copy of every order was forwarded to the Inspecting Engineer who was at the head of the inspecting department, which department was directly under the General Purchasing Officer. The order form, when received, was carefully noted by the Inspecting Engineer or by one of his assistants, and a short form was filled out making notation of the various papers.

specifications, drawings, etc., which would be needed in handling the inspection of the order, so that when the material was reported as ready, no time was wasted in getting together the papers. Frequently this investigation developed uncertain points which, if they had arisen later, might have delayed the furnishing of the material.

The Inspecting Engineer, on the receipt of this order form, immediately sent to the contractor a form letter asking to be advised when and where the material would be ready for inspection. On receipt of reply to this letter (which, by the way, was frequently not forthcoming until a second or even a third request), all the necessary papers were sent to our nearest inspector, with instructions to keep in touch with the contractor and make the inspection on the date specified. The inspector, if he found the material satisfactory, filled out a form giving the contractor authority to ship the material, one copy of this authority being forwarded to the Inspecting Engineer and another copy being forwarded to one of our agents at the seaport through which the material would be shipped, in order that he might keep track of it and see that it went forward promptly.

It has always been a rule to allow our inspectors very small latitude in the matter of departures from specifications, and any such departures were immediately reported to the Inspecting Engineer, to be passed on by him, or by the General Purchasing Officer. In this way we were reasonably sure that inspections of similar material from different parts of the country were being handled in exactly the same manner.

In certain cases, before shipment was authorized, it was necessary to have samples of material analyzed or subjected to certain physical tests. Samples were not taken until the material was prepared for shipment and, when taken, the containers were sealed by our inspector and properly marked so that there would be no danger of the substitution of other material. These samples, having been taken by our inspector, were forwarded either to Washington for analysis and test by one of the technical government bureaus, or to Pittsburg, where we maintained a small laboratory of our own. As soon as the samples were reported on, the contractor was notified to make shipment, if the result was satisfactory; or he was advised of

the rejection of the material, if the result was not satisfactory. In either case a printed form was filled out and the information as to the acceptance or rejection was furnished to the contractor and to the authorities on the Isthmus, so that they might know the status of the particular order. Each inspection was covered by the inspector in a report, which merely consisted in his filling out certain blanks replying to certain printed questions, which were indicated on the report form. These answers included all the data which were necessary to adjudicate the order finally and were found preferable to the ordinary typewritten report, from which essential data were frequently omitted.

In connection with the inspections by the Isthmian Canal Commission, it was found necessary, as work proceeded, to build up quite a large inspection force, the members of which were directly employed by the Isthmian Canal Commission and were under the supervision of the Inspecting Engineer. In addition to these inspectors, who were stationed at various large cities throughout the country, the Isthmian Canal Commission was authorized to ask the various District Engineer Officers of the United States Army to handle small inspections, and the assistance given by this branch of the service was material in permitting prompt handling of orders. The Isthmian Canal Commission has also worked in close harmony with the various technical branches of the government. A large proportion of our analytical tests and a great many of our physical tests were made by the Bureau of Standards, the Bureau of Chemistry, and the Bureau of Mines. Frequent expert assistance was also given by the Bureau of Forestry and the Bureau of Plant Industry. The work of these departments is of the highest grade. If a rejection based on the report of one of the bureaus was complained of by the contractor, he was always given the privilege of consulting the particular bureau from which the report originated. There are very few, if any, instances on file where the contractor did not finally accept the report of the Bureau and indicate his belief that the work of the Bureau could not be questioned. As one instance of the assistance given, it is noted that all the technical work in the inspection and testing of the cement furnished to the Panama

Canal was done under the direction of the Bureau of Standards. As the shipments of cement at one time amounted to 7,000 barrels per day, and the total amount of cement furnished was approximately 6,500,000 barrels, it can readily be seen that the work involved was of no light character.

The system just described has reference to the usual inspections covering ordinary supplies. In connection with large contracts, which required considerable time for execution and involved a special force for the inspection work at shops and mills, a slightly different system was followed. In these cases the work was assigned to an Assistant Engineer who reported either direct to the General Purchasing Officer or to the authorities on the Isthmus. This Assistant Engineer was in charge of the local work of inspection and had under him such inspectors as were needed, such assistance of course being rendered by the regular inspecting force under the Inspecting Engineer as could be given from time to time. Some of the works carried on under these special inspecting forces were the inspection of the lock gates, the emergency dams, the electrical installations on the Isthmus and the sea-going dredges and other large floating equipment. It is noted however that the bulk of the work fell directly under the Inspecting Engineer.

FOLLOW-UP SYSTEM.

When an order was placed, a copy of this order was sent to the "follow-up" or "punching" desk. On receipt of this copy it was examined, the date of delivery called for was noted, and the urgency, and the character of the material were taken into account.

Based on these a note was made at an advanced date in a diary kept for that purpose, to look up the order referred to. When the date arrived the order was examined, the status was determined and the contractor, in case circumstances seemed to warrant, was requested to expedite the work. A note was again made on a further advanced date and the order was again called up at that time. In this way every urgent order was closely followed and every effort was made to expedite delivery.

The set of orders designated for this room was kept on

file there, and as the shipping papers were received, notations were made on the orders to indicate what parts of the material had gone forward. When the order was completed this copy was transferred from the active file to the completed file, and it was therefore possible at any time by reference to the active file, to find out exactly how many orders were still outstanding and what amount of material had been shipped on each one.

RECORD ROOM.

The system of filing and keeping track of the records was not in accordance with modern ideas, but, in view of the peculiar circumstances, was found perfectly satisfactory. All requisitions received from the Isthmus bore a certain number. So far as correspondence with the Isthmus was concerned, any item mentioned in that requisition was always referred to by the requisition number and the item number thereon. Until a particular item of a requisition was included in a printed circular or was covered by an order, all papers relative to that particular item were filed on the requisition file. As soon as the item was placed in a circular, a file bearing the circular number was started, and, until an order was placed, the circular number and class number of the item were generally referred to. When the item was covered by an order, all correspondence bore, as a file record, the order number. There were, in addition to correspondence in connection with items requisitioned for from the Isthmus, a great many letters and documents which bore no particular reference to requisition, circular or order number. These were filed in miscellaneous files with cross-index cards. A card record of various contractors and orders placed on them was kept in the file room as well as a card record of all orders covering any particular class of material. These card records were as brief as possible and any special information was obtained by referring to the file itself.

All through the work an attempt was made to keep every one interested advised of the status of the various orders, and also, by reference to various offices interested, to check the orders as placed and to make sure that there were no errors. The following system was adopted: A copy of the requisition prepared on the Isthmus was forwarded to the division on the

Isthmus whose requisition had been consolidated therein. If any error was noted in the consolidation it was the duty of the division making the original requisition to call attention promptly to it. On receipt of the requisitions in the United States the various items and specifications were carefully noted by the proper clerk, and, if any discrepancy was discovered which could be rectified in the Washington Office, it was promptly done, and the authorities on the Isthmus were notified of the action taken. If the discrepancies were of such a nature that there was considerable doubt as to what was desired, the matter was referred to the authorities on the Isthmus, either by letter or by cable as the urgency demanded. On the issuance of a circular or on the issuance of a letter asking for prices, a copy of such circular or letter was immediately sent to the authorities on the Isthmus. Likewise when an order was placed, two copies of the same were forwarded to the Chief Quartermaster, one copy being placed on his file and the other copy being referred to the division which made the original requisition. This order was checked with the original requisition and any errors were promptly reported.

On the first day of each month a report was submitted to the authorities on the Isthmus indicating what items, on requisitions received up to the beginning of the second preceding month, had not as yet been ordered. This statement was checked by the authorities on the Isthmus and in this way assurance was given that no items had been overlooked.

In the Washington Office the original requisition was placed in a separate binder, and, as the orders were placed, a notation of the order number was made against the particular item on the requisition. As the original requisitions were completed they were carefully examined for omissions, were removed from the active file, and placed in separate binders in the file room.

FORMS.

Throughout the work it was found that the adoption of form letters and reports was very convenient, and it is possible that, in the opinion of persons dealing with the Panama Canal, these forms may have been increased beyond any reasonable

amount. The great advantage is that there is no danger of omitting information which is desired, and there is moreover no reason for including extraneous and unnecessary data. These forms have been found extremely valuable in the work and have materially assisted in the proper handling thereof.

CONCLUSIONS.

The experience gained from several years' connection with purchasing supplies for the Panama Canal has convinced the writer that there are certain general principles which must be observed in government purchases. Some of these are almost axiomatic and others will doubtless not be in accordance with the view of either the seller or of many government officials. These principles as I see them may be briefly stated as follows:

> Specifications covering the physical and chemical requirements desired should be drawn with a view not only of obtaining satisfactory material but also of obtaining the cheapest material which under the circumstances will meet the needs.

It is noted that the statement is made that the cheapest material acceptable under the conditions of its intended use should be obtained, and not that the cheapest article must be taken. There is a very widespread but mistaken idea that the low bidder on government work is in every case entitled to the award. If the statement were "the low bidder under and in accordance with the specifications", there would in the opinion of the writer be some virtue in the claim. Even here, however, other conditions must be considered as, for example, the former performance of contracts by the same bidder, his known ability to perform the work, his available facilities for carrying it out and a consideration as to whether the price bid is sufficient to permit furnishing the material desired without loss.

The last consideration is desirable but is not without difficulties in execution. A government official is not authorized to reject a bid, nor even to permit a bidder to withdraw a bid, unless it can be clearly shown that it was based on a clerical error. A plea that the conditions were not properly judged, or that certain items were forgotten, is not sufficient to permit a

bidder to withdraw. On the other hand, even if the price does appear unwarrantably low, there may be reasons which enable or induce the bidder to offer his material at an apparent losing figure. For example, he may have surplus stock which he desires to clear, or he may have purchased raw material at a former very low figure. Frequently, in connection with the Panama Canal, it is known that contracts were taken at an apparent loss, merely for the sake of the advertisement which was obtained for the contractor by his having furnished material for this work.

If it could be legally done, the writer is of the opinion, however, that if a bid is shown to be unwarrantably low, the award should not be made to such bidder, as it is almost invariably the case that difficulties result from such a contract.

Specifications should cover the material desired. They should not include any unnecessary requirements, nor should they omit any essentials. The cheapest material for any purpose depends almost entirely on the conditions under which it is used. For permanent shop equipment the cheapest tool is determined by first cost, life and a consideration of the expenses which may be involved in replacement; for temporary or construction work on the other hand where the life is limited not by wearing out from reasonable use, a lower price tool is cheaper. For example, it was found much more economical in the long run, for construction work on the Canal, to use a fairly cheap shovel than a high priced one which would probably under proper use outlast the former two to one. This was due to the fact that a large proportion were unavoidably either lost or broken from misuse before they would have been discarded on account of having been worn out.

> Specifications in ordinary cases should be so drawn as to permit the use of standard commercial products.

In many cases the ordinary commercial product will meet the needs, and, in such cases, the demand for articles to meet special specifications adds materially to the price and delivery. The increased price is in many cases not an equivalent of the increased value of the article, for as every manufacturer knows,

even a slight change in manufacture, disarranges schedules and upsets the routine work of factory and shop, and this disarrangement is reflected in the price of the material. Moreover, standard products are the result of long experience, and their methods of manufacture are reduced to a routine which enables their production at a minimum price.

It is not intended that material should be purchased without specifications, but with almost every article there are certain standard methods of manufacture which can be readily specified and which will permit competition from several responsible firms.

> The contract clauses should be so drawn as to protect the contractor as well as the government.

Too many government officials adopt the principle that a contract is for the benefit and protection of the government only. If a bidder in preparing his prices realizes that his rights, if a contract is entered into, are not fully guaranteed, he will increase his tender accordingly. On the other hand, if he sees that his interests are thoroughly protected under the terms of the contract, he will reduce his price to the minimum. It would therefore appear that in the end it is to the interest of the government to give full protection under the terms of the contract to the contractor.

> Care should be taken so far as practicable to include no unnecessary or uncertain conditions, either in the specification or in the terms covering the performance of the contract.

One of the most frequent complaints received from contractors whether for government work or work for private individuals is that specifications are frequently loosely drawn and contain uncertain conditions. In bidding on such specifications the contractor must cover himself for any contingency which may arise, and it therefore follows that each uncertain or unnecessary condition adds just that much to the price of the contract. It is unfair to the contractor to require him to take all the risks, and therefore the number of such risks should be reduced to a minimum.

> In awarding contracts it is to the best interests of the government in the long run to follow certain definite rules, which in time become known to bidders, and the known observance of which will permit reputable manufacturers to reduce their prices to the lowest practicable figures.

The subject of permitting modification in bids after an opening is one which is open to a great deal of discussion. Many officials feel that, if they can induce bidders to decrease their bid, they have a perfect right to do so and that it is to the best interests of the government to exercise this right. On the other side it is contended that such modification immediately results in bidders submitting a price higher than they actually contemplate asking, with the expectation, on being requested to reduce their bid, of quoting the figure which they otherwise would have quoted at the outset.

Under the work for the Panama Canal, the rules relative to awards have been very stringently observed, even to the point sometimes of paying a considerably higher price where a lower price might have been obtained, if a bidder had been permitted to modify his original proposal. It is these exceptional cases which are generally seized by the official who believes in permitting modifications, and these definite losses are rather hard to combat, in view of the fact that the economies obtained by the other method do not appear in actual figures.

As in the case with rules of all kinds, no trouble arises if they are strictly followed, difficulties occurring only in connection with variations from the rules.

> In enforcing the terms of the contract, it should be realized that the contractor and the unsuccessful bidders have certain rights which should be considered, and that the observance of such rights will in the end be beneficial to the government.

While the above rule has reference more to the inspection of material under a contract than to the purchasing of material, yet it has a re-active effect on future purchases, in that contractors, knowing that modifications are frequently made, may submit bids with the assumption that, in carrying out any con-

tracts based thereon, they will be permitted to make such modifications.

For this reason it is necessary in carrying out a contract to see that all the terms thereof are followed so far as it is possible to do so, and this rule should be applied against the government as well as against the contractor. In other words the government official has no more right to demand something from a contractor which is not called for in the terms and conditions of his contract, than he has to permit the contractor to omit certain requirements of that agreement. The average contractor doing business with the government cannot understand why he is not permitted to substitute material which, in his opinion, is just as good as that which the order calls for. He fails to consider that, although the material may in fact be equally good, yet it is not the material called for, and the mere fact that he wishes to substitute it indicates that he can do so at less expense to himself. If other bidders had been permitted to submit a price on the substitute article, they might have been able to decrease the amounts of their bids, and the award might not have gone to the contractor who actually received the order. As indicated before in this paper, it must be assumed that the government official, in preparing his specifications, knows what is needed.

> The final decision in case of any dispute between the parties to a contract should, where not otherwise provided by law, devolve on some government official of as high a rank as is consistent with the amount involved, and as the interests of the government will permit.

This is a great stumbling block to all contractors, their claim being that, where the final decision is placed in the hands of an employee of the opposite party to the contract, he, the contractor, cannot receive impartial treatment. Unfortunately such a claim is only too well justified by experience, but, on the other hand, so far as the government is concerned, no other course is practicable. The final arbiter should preferably be some one superior to the official who has drawn the contract and who is in direct charge of the work. In the majority of cases, however, this course

cannot be followed out and the final decision in matters of fact must be left to the official in charge of the work. It is one of those uncertainties which cannot be avoided.

The questions for decision referred to in this comment are questions of fact, as questions of law which may come under dispute may be settled by courts or otherwise as provided by law. However, in questions of fact where the contract makes any particular person the arbiter, the courts invariably rule that they cannot go behind his decision, unless the decision is shown to be a gross error in judgment, or in case of fraud.

The government official designated as the arbiter in cases of this kind is more than an official of the government. He is a judge and should be, as far as it is humanly possible, impartial in his conclusion, whether such conclusion is against the interests of the government or not, and no conclusion should be given without complete investigation. The greater the responsibility is in a case of this kind, the more necessary is it for the official to rest his judgment on the most complete data.

Paper No. 9

THE CLIMATOLOGY AND HYDROLOGY OF THE PANAMA CANAL.

By

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INTRODUCTION.

The data used in the preparation of these papers are compiled from the records of the Isthmian Canal Commission, the Panama Canal, the Panama Railroad, and the Old and New French Companies, but are based principally on the records obtained under the direction of the Isthmian Canal Commission since the American occupation of the Canal Zone.

It is not the intention to give a discussion on the engineering problems pertaining to the construction of the Panama Canal, but to present the meteorology and hydrology of the canal in a comprehensive manner.

The Canal Zone is a strip of territory 10 miles wide and about 50 miles long, ceded to the United States by the Republic of Panama for the construction, maintenance, and operation of an interoceanic canal. Its landed area is approximately 436 square miles, about one-half of which lies in the northeasterly portion of the valley of the Chagres River. Geographically it lies between longitude 79° 29′ 30″ and 80° 00′ west, and latitude 8° 52′ and 9° 26′ north. Limon Bay and the Caribbean Sea lie to the northward, and Panama Bay forms its southern boundary. On the right and left are the Isthmian land masses that join the North and South American continents.

The Pacific entrance of the Panama Canal at Balboa is about 23 miles east of the Atlantic entrance near Cristobal. The dominating feature of the Canal is Gatun Lake, formed by damming the waters of the Chagres River at Gatun. This

lake has an area of 164 square miles at elevation + 87 feet above sea-level, and contains 192.24 billion cubic feet of water.

The drainage of the Canal Zone for about three-fourths of its width is effected through the Chagres River and its tributaries, to the Caribbean Sea, and for the remaining one-fourth through the Rio Grande and its tributaries, to the Pacific. The drainage area of the Chagres above Gatun is 1320 square miles. Due to violent storms over the headwaters of this river, it is subject to very sudden rises, during which the discharge, in a few hours, is enormously increased. The drainage area of the Rio Grande and its tributaries is about 65 square miles.

Geology.

The Canal prism cuts the Cordillera at Culebra, about nine miles from the Pacific coast.

On the Atlantic side of the "divide" the formation is mostly sedimentary, while on the Pacific side it is volcanic. The composition of the materials underlying Gatun Lake is such as to reduce loss by seepage to a minimum. The low-lying valleys of the Chagres and Rio Grande, near their mouths, are filled with alluvium from the bottoms of the rock gorges to a little above sea-level. Both the Atlantic and Pacific coasts are fringed with a coral formation of comparatively recent date, which in the vicinity of the large rivers extends inland several miles.

Topography.

Local topography has an important bearing on climatic conditions, especially in tropical countries, where weather conditions are of remarkable sameness, except when influenced by variation in altitude, the trend of mountain ranges or the proximity of large land or water areas.

The coastal plain type of topography is fairly well represented along the Atlantic Coast of the Canal Zone, but low hills begin to appear a few miles inland, while in the central and southern sections of the Canal Zone the hill type of topography prevails. These hills have conical or rounded tops, are clothed with vegetation, and, with few exceptions, are under 1000 feet in elevation. The Continental Divide crosses the line of the Canal about nine miles from the Pacific Coast, and thirty miles from the Atlantic. The ridge crest within the Zone varies

in elevation from about 260 feet to something near 1000 feet. It lies approximately at right angles to the direction of the prevailing winds that blow from off the Atlantic, and the Atlantic (windward) slope of the Continental Divide has more abundant rainfall than the Pacific slope. Variations in altitude are too slight to affect the temperature very appreciably. As average temperatures decrease approximately one degree Fahrenheit with every 330 feet increase in elevation, the maximum temperature depression in the Canal Zone on account of altitude is only about three degrees Fahrenheit.

The effect of the Caribbean Sea lying to the windward is felt in the climate of the Atlantic Coast, which resembles closely the moist equable oceanic type, while climatic conditions in the interior and on the Pacific slope exhibit many of the characteristics of the continental type, as the prevailing winds over these sections blow from off the Isthmian land areas.

Following the route of the Canal from the Atlantic to the Pacific Coast the physical conditions may be described briefly as follows:

From near the mouth of the Mindi River, where the Canal enters the mainland, its course is through the large fresh-water swamps of the Mindi until it reaches Gatun, a distance of about three miles. This plain is enclosed by hills rising from 50 to 200 feet above sea level.

From Gatun to Bohio, a distance of about nine miles, it follows the valley of the Chagres through the swamps of Calle Bruja, the lower Gatun River, Ahorca Lagarto and the lowlands at the entrance of the Trinidad Valley and the extensive swamps of Peña Blanca. The surface of the ground is elevated only a few feet above sea level.

At Bohio there is a sudden contraction of the valley of the Chagres, caused by the Monte Lirio-Bohio ridge line. After passing Bohio the country opens out again into a well defined valley. A second contraction of the valley is met with at San Pablo, in passing through which the waters of the Chagres form a narrow arm of the lake reaching to Gamboa, and thence up the valley to the Gatuncillo, which joins the Chagres about one and one-half miles below Alhajuela, and is the ordinary limit of back-water from the Gatun Lake. The topog-

raphy rises gradually from Bohio until the foothills of the Continental Divide are encountered at Gamboa.

Passing through the foothills of Gamboa a series of crests is encountered leading on to the summit of the Continental Divide at Culebra. The distance through the divide, or Culebra Cut, from Gamboa to Pedro Miguel, is about 8 miles.

From Pedro Miguel to Balboa the route follows the valley of the Rio Grande for a distance of about 8 miles. The slope of the Rio Grande for half its distance to the bay is much more rapid than that of the Chagres Valley, but the physical characteristics are the same. From the junction of the Pedro Miguel River the Rio Grande is a tidal estuary filled and emptied twice each day by the tides.

METEOROLOGY.

Stations and Equipment.

Three first-class meteorological stations have been maintained since 1907—Ancon, Culebra and Colon*. Each is supplied with a full complement of instruments of types similar to those used by the United States Weather Bureau. The regular equipment at the first-class stations consists of mercurial barometers for measuring the atmospheric pressure, an anemometer and anemoscope for measuring wind velocity and direction, a whirling apparatus for obtaining the relative humidity and the dew point, maximum, minimum and standard thermometers, a tipping-bucket rain gage, and a sunshine recorder, and the following automatic instruments: A meteorograph for recording the rainfall, sunshine, wind velocity and wind direction; a thermograph for recording air temperatures; a hygrograph for registering the relative humidity; and a barograph for recording the atmospheric pressure. In addition to the above, Ancon and Colon are supplied with evaporation pans for measuring the loss of water by evaporation.

Records of the wind direction and velocity are obtained at Gatun and Pedro Miguel lock sites and at Gamboa, and temperature records are kept at Gatun and Alhajuela.

* The meteorological station at Culebra was discontinued on September 12, 1914, and the Ancon station was moved to Balboa Heights on October 1, 1914.

About 25 rainfall stations are maintained. Approximately half of these are equipped with automatic tipping-bucket rain gages and the remainder with standard gages. With the advance or completion of various items of Canal construction work, it became necessary to discontinue certain rainfall stations, especially those located within the present area of Gatun Lake, but new stations were established on the upper arms of the lake or on tributary streams. The result has been that the total number of stations in operation has not varied greatly from year to year.

Climate.

As previously noted, the Canal Zone lies wholly within the Torrid Zone and very close to the thermal equator. Its climate may be characterized as warm, humid and equable. The year is divided into a dry season of four months duration, and a rainy season extending over the remaining eight months of the year.

Average temperatures are remarkably uniform from month to month. The diurnal range in temperature is small, and sudden changes seldom occur. The climate along the Atlantic Coast is of the oceanic or marine type, characterized by small range in temperature, relatively high wind movement, high humidity and excessive rainfall; while climatic conditions over the interior and along the Pacific Coast resemble more closely the continental type. This difference is due primarily to the prevailing northerly direction of the wind throughout the greater part of the year.

The filling of Gatun Lake to operating level, completed in January, 1914, wrought important changes in the lower section of the Chagres River basin. The interesting question arises as what effect the creation of this artificial inland sea covering an area of 165 square miles will have upon the climate of the Isthmus.

Sufficient records are not yet available upon which to base any definite conclusions, but it is certain that no marked climatic changes will take place, altho slight increases in humidity, cloudiness and rainfall may be expected on the leeward (southern) side of the lake. There should be a slight increase in wind velocities over the lake surface and con-

tiguous land areas, and slightly more uniform temperatures will prevail over the lake surface.

Practically no climatic changes will be felt on the windward (northern) side of the lake.

In the following pages climatic conditions on the Isthmus will be treated more in detail under appropriate headings.

Precipitation.

Quoting in part from Mr. C. M. Saville in a paper on the "Hydrology of the Panama Canal" read before the American Society of Civil Engineers:

> "The cause of rainfall is to be found in the operation of certain general principles of physics, influenced more or less by local conditions. Rainfall is due to the precipitation of water vapor in the atmosphere which has been derived primarily from the ocean by the process of evaporation. Whenever from any cause the moisture-laden air is sufficiently cooled, condensation and consequent precipitation take place. Three processes are primarily concerned in the production of rain, acting either singly or in combination. These factors are:
>
> 1. Convective currents
> 2. Hills and mountains, which cause deflection of atmospheric currents
> 3. Cyclonic circulation.
>
> "As the Isthmus of Panama is in that section of the globe where the influence of convection is very great and where cyclonic disturbances are almost unknown, it follows that the greater part of the Isthmian rainfall must be attributed to the first two processes enumerated above".

The season of the year from January to April inclusive is commonly recognized as the dry season on the Isthmus, and the remaining months of the year constitute the rainy season. The lines of demarcation between the dry and rainy seasons are neither constant nor always clearly marked. Occasionally the dry season begins as early as the first of December, while in other years rainy weather may continue until the first of January, or even later. There was no dry season worthy of note in the year 1909, as heavy rains fell during each of the dry

season months. The rains frequently continue, along the Atlantic coast and toward the headwaters of the Chagres River, for some time after dry season weather has set in over the remainder of the Isthmus. These late rains on the upper watershed account for the occasional December or January freshets

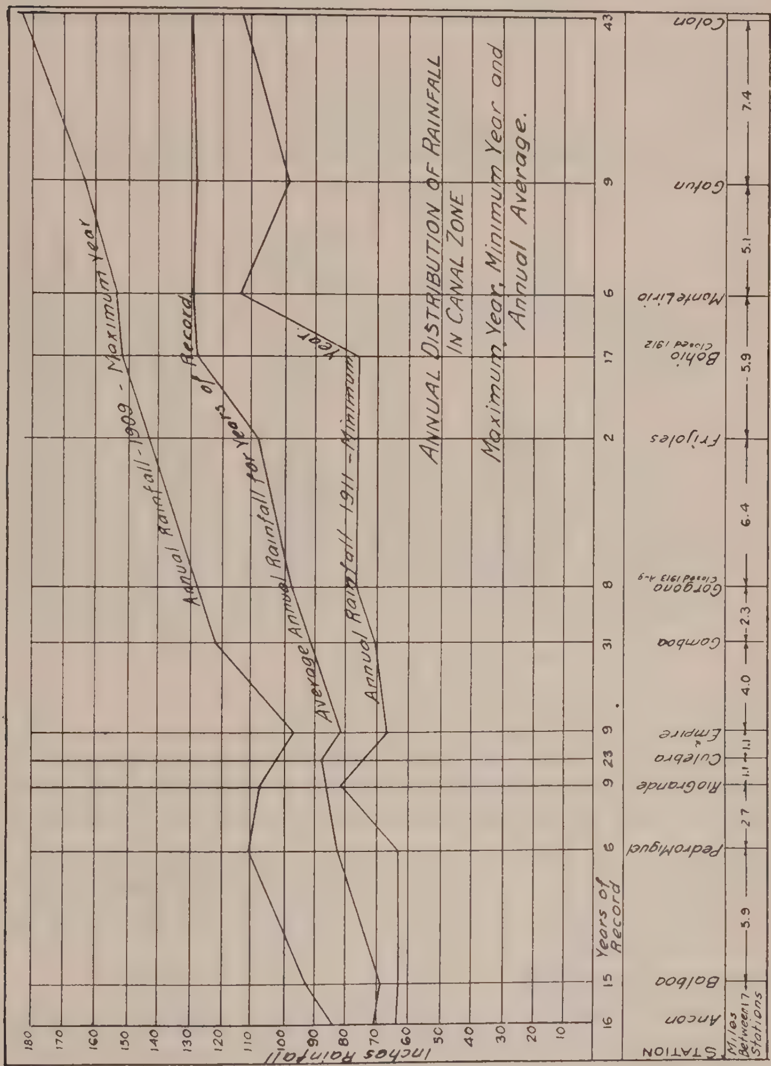

Fig. 1.

in the Chagres River, at times when there has been little or no rain in the immediate vicinity of the Canal Zone.

Distribution.

Rainfall is heaviest along the Atlantic Coast and in certain sections of the upper Chagres River basin, diminishing gradually as the Pacific Coast is approached. Our rain-bearing winds usually blow from off the Atlantic in a southerly direction and most of their moisture is dropped on the Atlantic

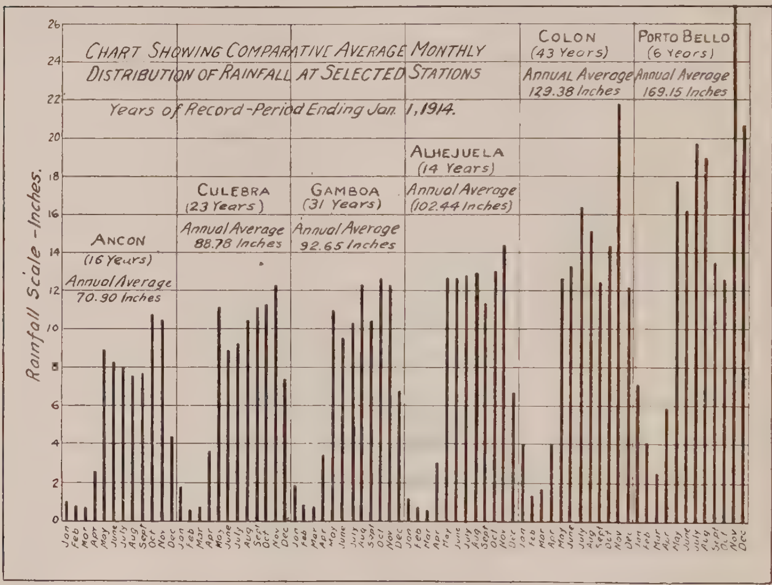

Fig. 2.

slope before reaching the Continental Divide. The annual rainfall ranges from approximately 130 inches at Colon, and 170 inches at Porto Bello, situated on the Atlantic Coast about 20 miles east of the Canal entrance, to 70 inches at Ancon and Balboa, on the Pacific side. Figure 1 shows the annual distribution of rainfall across the Isthmus, and illustrates graphically the steady decrease in annual rainfall along the line of the Canal, from the Atlantic Coast to the Pacific.

Monthly Distribution.

An examination of Fig. 2, which gives the average monthly distribution of rainfall at selected stations, shows two periods

of maximum rainfall, the first in May and the second in November, although November usually is the month of heaviest precipitation, and March almost invariably is the month of lightest rainfall.

Tables 1, 2 and 3 give the average monthly rainfall in the Pacific, Central and Atlantic sections, for the 10-year period from 1905 to 1914 inclusive, while Tables 4-A and 4-B give the

TABLE 1.

THE PANAMA CANAL

AVERAGE MONTHLY RAINFALL - PACIFIC SECTION

1905 - 1914

Values in Inches.

Month	(2) 1905	(4) 1906	(3) 1907	(4) 1908	(4) 1909	(5) 1910	(5) 1911	(5) 1912	(5) 1913	(5) 1914
Jan.	1.90	.58	.21	.27	2.82	1.85	.31	.01	1.45	.71
Feb.	0	.55	.06	.20	2.68	.88	2.14	.23	.68	.07
Mar.	.22	.17	.02	.07	.27	1.98	.07	.01	.15	T
Apr.	3.57	(3) 6.36	.06	1.32	2.68	4.60	5.74	3.52	.61	3.25
May	10.66	8.28	5.96	11.32	8.67	10.67	11.30	8.39	10.89	10.01
June	(3) 9.69	8.56	13.26	7.01	11.36	11.83	4.18	7.10	8.37	8.29
July	7.08	10.28	5.96	8.64	10.30	10.86	6.62	9.81	5.40	5.42
Aug.	(2) 8.43	8.86	9.17	9.73	7.87	10.78	7.27	9.43	6.46	7.12
Sept.	(3) 9.24	4.61	11.04	8.68	8.25	7.49	7.59	11.74	9.33	8.09
Oct.	10.20	4.91	11.51	8.32	14.70	12.08	11.73	13.80	9.61	7.30
Nov.	6.64	14.53	9.39	7.64	19.62	7.94	8.69	7.97	9.68	10.72
Dec.	4.53	6.31	3.51	6.14	12.18	9.93	1.57	4.58	3.33	7.05
Year	72.16	74.10	70.15	69.34	101.40	90.84	67.21	76.59	65.96	68.03

Averages based on records from all stations in operation. Stations given equal weights.

Figures in parentheses at head of columns indicate number of stations in operation.

estimated average rainfall over the Gatun Lake basin and the Chagres River basin above Alhajuela. Table 5 gives the average monthly rainfall at practically all the rainfall stations.

Hourly Distribution.

A large percentage of the Isthmian rainfall comes in the form of afternoon tropical showers. The period from 2:00 P. M. to 3:00 P. M. is the hour of heaviest rainfall as a general rule. The curves of average hourly rainfall show two periods

TABLE 2.

THE PANAMA CANAL

AVERAGE MONTHLY RAINFALL - CENTRAL SECTION

1905 - 1914

Values in Inches.

Month	(3) 1905	(5) 1906	(7) 1907	(11) 1908	(12) 1909	(12) 1910	(12) 1911	(11) 1912	(11) 1913	(10) 1914
Jan.	4.27	1.01	.37	1.24	4.33	2.30	.28	.44	2.21	.58
Feb.	.37	.76	.37	.38	3.49	3.21	1.55	1.10	1.12	.62
Mar.	.81	.62	.44	.89	1.28	4.28	.59	.09	.31	.25
Apr.	1.72	7.21	.27	2.63	4.92	5.59	4.43	1.51	1.77	1.83
May 15	.66	8.55	6.38	16.06	11.14	10.92	14.71	9.45	14.79	11.14
June	(4) 6.60	9.41	(8) 12.46	10.67	12.27	11.98	7.42	11.65	10.03	12.48
July	6.13	17.53	(9) 9.71	(10) 10.16	11.19	16.43	6.59	11.11	6.58	5.43
Aug.	13.00	(6) 13.95	11.36	12.97	8.76	12.13	8.41	12.45	11.69	10.49
Sept.	8.05	8.76	12.87	(11) 11.33	9.94	15.25	6.56	12.16	(10) 9.75	13.45
Oct.	(5) 13.05	8.12	16.50	11.85	17.33	15.06	14.25	14.81	9.37	15.66
Nov.	8.26	17.94	9.40	11.33	30.~~40~~	~~1~~5.62	13.24	11.03	14.55	9.35
Dec.	6.10	10.94	(11) 2.87	5.11	14.86	16.43	1.05	3.68	2.76	4.85
Year	84.02	104.80	83.00	94.62	129.91	129.20	79.08	89.68	84.93	86.13

Averages based on records from all stations in operation. Stations given equal weights.

Figures in parentheses at head of column indicate number of stations in operation.

of minimum fall, one around 9 A. M. or 10 A. M., and the other between 10 and 11 P. M.

Nearly half of the total annual rainfall occurs at night along the Atlantic Coast, while at stations in the interior and on the Pacific Coast only about 25 per cent of the annual total falls at night.

TABLE 3.

THE PANAMA CANAL

AVERAGE MONTHLY RAINFALL - ATLANTIC SECTION

1905 - 1914

Values in Inches

Month	(2) 1905	(2) 1906	(3) 1907	(3) 1908	(4) 1909	(5) 1910	(5) 1911	(4) 1912	(4) 1913	(4) 1914
Jan.	8.52	1.94	2.61	3.77	11.94	7.08	1.11	.62	5.72	1.56
Feb.	1.56	1.24	1.63	1.18	4.25	4.10	3.24	2.02	2.72	1.38
Mar.	.45	1.90	2.52	3.12	2.82	(4) 7.64	1.59	.58	.92	1.02
Apr.	2.02	6.23	1.18	1.36	6.60	5.25	5.16	1.58	3.91	4.34
May	25.88	11.04	7.57	(4) 20.73	8.35	12.08	18.44	13.49	22.24	14.52
June	9.28	13.57	15.69	13.92	17.54	13.04	15.42	17.34	10.92	14.96
July	11.08	(3) 17.56	14.31	14.16	15.96	(5) 20.40	11.77	16.51	14.30	8.30
Aug.	19.56	17.82	17.59	17.07	12.40	14.54	13.19	12.60	18.10	16.79
Sept.	8.56	14.04	10.92	10.18	11.71	11.41	11.22	11.05	10.79	(3) 13.01
Oct.	17.08	15.82	19.89	10.60	14.60	11.81	14.38	16.79	17.62	19.53
Nov.	17.40	24.94	14.51	30.48	38.48	24.69	(4) 18.71	22.17	21.86	15.84
Dec.	10.70	16.83	6.82	13.06	39.34	19.80	2.22	10.61	9.40	6.22
Year	132.09	142.93	115.24	139.63	163.99	151.84	116.45	125.36	138.50	117.47

Averages based on records from all stations in operation, except Bocas del Toro, the location of which is too remote from the Canal Zone to indicate conditions near the Canal entrance. Stations given equal weights. Figures in parentheses indicate number of stations in operation.

The following table shows the percentage of daytime rain fall (6 A. M. to 6 P. M.) at three selected stations:

Station	Per Cent Daytime Rainfall
Balboa—Pacific Coast	71%
Culebra—Continental Divide	81%
Colon—Atlantic Coast	54%

Based on six years' records—1908 to 1913.

Curves of average hourly rainfall are shown on Fig. 3.

Rainy Days.

The average number of days during the year with a measurable quantity of rainfall (0.01 inch or more) is about 260 on the Atlantic Coast, 210 at Culebra on the Continental Divide, and 180 on the Pacific Coast. November is usually the month of greatest rainfall frequency, and March the month of fewest rainy days.

Excessive Precipitation.

There are occasional exceptions, but the greater part of the rainfall on the Isthmus comes in the form of heavy tropical downpour of short duration and relatively limited extent.

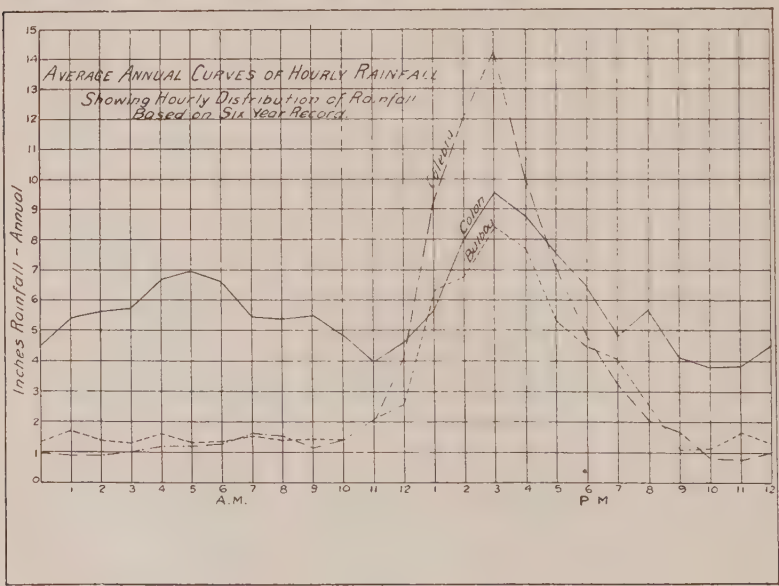

Fig. 3.

Late in the rainy season, or in November and December, rainstorms of a more general character and of longer duration are experienced. These may continue for 24 hours or longer and may extend over the entire Canal Zone and adjacent territory. The heaviest general rainstorm of record on the Isthmus occurred on December 2nd and 3rd, 1906. Rain began falling on the afternoon of December 2nd and continued steadily, though not at a remarkably excessive rate, for nearly 24 hours. The following table shows the amounts recorded at the various stations during this rain storm, which produced one of the largest freshets in the history of the Chagres River:

Station	Inches	Station	Inches
Balboa	2.41	Gamboa	6.29
Ancon	3.18	Alhajuela	8.19
Rio Grande	5.58	Bohio	6.13
Culebra	5.55	Gatun	10.48
Camacho	5.53	Brazos Brook	8.96
Empire	6.15	Cristobal	8.47

The extremely local character of many of the rains that occur on the Isthmus has been mentioned. An examination of the records shows some remarkable differences in the quantity of rain falling within narrow territorial limits. The following table gives a comparison of the rainfall at adjacent stations for selected showers:

Stations	Rainfall (Inches)	Station	Rainfall (Inches)	Distance Between Stations (Miles)	Date
Monte Lirio	6.76	Brazos Brook	.97	6	February 8, 1910
Gamboa	3.21	Empire	.52	4	July 3, 1910
Gatun Evap. Sta.	4.05	Gatun	.89	1	May 23, 1911
Gorgona	5.45	San Pablo	1.27	3.5	May 13, 1911
Miraflores	4.04	Pedro Miguel	.35	2	December 30, 1912
Empire	3.36	Culebra	.59	1	June 7, 1913
Brazos Brook	3.75	Colon	.31	3	December 1, 1913
Culebra	1.62	Rio Grande	.15	1	October 1, 1914

The following table shows the maximum precipitation of record on the Isthmus for various periods, while the maximum records for individual stations are presented in Table 6:

Period	Rainfall, Inches	Station	Date
5 min.	2.48	Porto Bello	November 29, 1911
1 hour	5.86	Balboa	June 2, 1906
24 hours	10.86	Porto Bello	December 28-29, 1909
Month	58.17	Porto Bello	December, 1909
Year	237.28	Porto Bello	1909

In this connection a comparison of the Isthmian maximum rainfall records with the records from other regions of excessive rainfall may be of interest. As shown above, the maximum 24-hour rainfall of record on the Isthmus is about 11

TABLE 6.

THE PANAMA CANAL
MAXIMUM RAINFALL IN CANAL ZONE
October 1, 1905 to December 31, 1914.

Values in Inches

	Five Minutes		One Hour		24 Hours (1)	
Stations	Inches	Date	Inches	Date	Inches	Date
Ancon (Oct. 1, 1905)	.64	Aug. 7, 1908	3.98	Oct. 9, 1911	7.23	May 12-13,1912
Balboa (June 10, 1906)	.90	May 12, 1912	5.86	June 2, 1906	7.57	Nov. 16-17,1906
Pedro Miguel (Jan. 1, 1908)	.60	Nov. 11, 1908	3.30	Aug. 27, 1908	4.56	Sep. 30-Oct.1,1909
Rio Grande (Dec. 29, 1905)	.75	July 24, 1908	3.10	Sep. 21, 1912	6.00	Dec. 2-3,1906
Culebra (July 1, 1906)	.64	May 2, 1908	3.69	Oct. 16, 1907	5.55	Dec. 3,1906(2)
Empire (July 18, 1906)	.60	July 25, 1906	3.63	Oct. 1, 1909	6.15	Dec. 3,1906(2)
Gamboa (Nov. 18, 1905)	.59	July 27, 1908	3.32	May 11, 1911	6.56	Dec. 2-3,1906
Alhajuela (Mar. 31, 1907)	.60	July 20, 1909	3.40	Dec. 28, 1909	8.19	Dec. 3,1906(2)
Bohio (4) Oct. 1, 1905)	.67	June 16, 1909	4.51	Aug. 7, 1908	8.65	Aug. 7-8,1908
Gatun (Aug. 24, 1907)	.62	Aug. 3, 1912	3.82	May 26, 1910	10.48	Dec. 3,1906(2)
Colon (Oct. 1, 1905)	.64	Aug. 25, 1909	4.90	Oct. 8, 1909	8.53	Dec. 2-3,1906
Porto Bello (May 1, 1908)	(3)2.48	Nov. 29, 1911	4.53	Nov. 29, 1911	10.86	Dec.28-29,1909

Dates in parentheses opposite station names refer to installation of automatic registers.

(1) For any 24 consecutive hours.
(2) No automatic record on this date. Total for 24 hours ending at noon.
(3) Approximate: Automatic record indistinct, due to unusually excessive rate of fall.
(4) Station closed January 1912.

inches. This record has been exceeded in certain localities in the southern section of the United States, although the annual average at stations on the Atlantic Coast of the Isthmus is higher than the annual rainfall anywhere in the United States. A number of the heaviest rainstorms of record in either hemisphere are listed below:

Station	Date	Amount Rainfall Inches	Duration Hours
Porto Bello	Dec. 28-29, 1909	10.9	24
St. George, Georgia	Aug. 28-29, 1911	18.0	17
Alexandria, Louisiana	June 15-16, 1886	21.4	24
Fort Clark, Texas	June 14-15, 1889	21.3	22
Mata Gordo, Texas	Apr. 30—May 1, 1911	15.71	24
Cherrapunji, Assam	June 14, 1876	40.8	24
Baguio, Philippine Islands	July 14-15, 1911	46.0	24

It is probable that quantities of rain greater than any listed above have fallen over very limited areas in the southwestern section of the United States from water spouts, but no records are available of actual measurements of the precipitation from storms of this character.

The average rainfall over a small area in the Hill district of Assam, British India, is about 475 inches per year, the heaviest of any known region in the world. More than 400 inches of this annual total falls during the five months of the summer monsoon.

The record of 46 inches of rain falling at Baguio, P. I., in 24 hours during the passage of a severe typhoon is, so far as known, a world's record for a period of 24 consecutive hours.

Air Temperature.

Average air temperatures on the Isthmus change very little from month to month. The highest average temperature usually occurs toward the end of the dry season, and the lowest, near the end of the rainy season. April is the month of highest average temperature, and November the month of lowest temperature. Average annual temperature curves for the three stations are shown on Fig. 4, while the monthly means are given in Table 16. Much other meteorological data for the three stations are given in Tables 13, 14 and 15.

TABLE 7.

THE PANAMA CANAL

PANAMA (ANCON) MONTHLY RAINFALL
PACIFIC COAST

(Inches)

Year	Jan'y	Febr'y	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Year
1879	0.04	2.52	5.71	5.55	10.28	6.46	7.91	7.24	9.02	9.80	19.21	0.98	84.72
1880	1.89	0.12	0.16	1.61	4.45	5.00	9.88	11.46	7.91	11.81	6.46	5.51	66.26
1881	0.16	0.16	0.35	3.23	10.35	13.78	7.20	4.49	8.94	9.68	9.72	2.48	70.54
1882	0.00	0.12	0.00	0.98	5.24	6.18	5.35	4.05	4.05	6.69	10.91	2.01	45.58
1898	--	--	--	--	---	---	3.35	6.89	7.94	13.48	11.13	1.89	---
1899	5.61	1.17	2.41	0.00	9.58	8.48	8.21	8.60	6.15	11.99	8.93	4.35	75.48
1900	0.76	0.00	0.00	2.25	11.22	8.93	15.82	6.00	7.76	20.27	13.01	1.85	87.87
1901	0.00	1.11	0.00	0.25	11.08	12.65	14.11	8.67	15.06	13.77	12.40	2.32	91.42
1905	--	--	--	--	---	7.33	4.31	5.31	7.46	8.49	8.81	4.04	---
1906	0.43	0.33	0.05	7.77	10.68	8.57	9.01	6.43	4.83	4.35	13.57	5.52	71.54
1907	0.29	0.04	T	T	4.44	12.64	4.28	7.46	11.14	9.26	10.51	3.46	63.52
1908	0.12	0.24	0.03	1.37	7.64	4.28	6.83	11.48	5.93	8.79	9.12	4.16	59.99
1909	2.90	2.90	0.18	2.92	9.10	9.90	9.01	6.84	3.86	8.77	15.14	12.39	83.91
1910	1.22	0.43	1.83	3.71	9.89	8.82	9.26	12.00	4.84	8.86	4.29	10.63	75.78
1911	0.83	2.75	0.26	6.34	11.04	3.40	5.78	7.21	6.03	10.90	7.57	1.99	64.10
1912	T	0.08	0.01	2.68	10.71	5.80	10.25	6.33	8.38	17.89	6.38	3.27	71.78
1913	.63	.22	.43	.03	8.27	8.15	4.85	8.20	11.43	8.30	10.63	4.84	65.98
1914	.32	.02	T	4.80	6.98	7.28	4.32	6.09	9.60	6.44	10.35	8.28	64.48

Note: Station moved to Balboa Heights, October 1, 1914.

TABLE 8.

THE PANAMA CANAL

ALHAJUELA — MONTHLY RAINFALL

UPPER CHAGRES RIVER (INCHES)

Year	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Year
1889							11.69	10.19	8.07	11.85	10.78	1.89	
1900	1.81	0.04	0.04	4.09	10.19	17.84	19.73	10.55	17.21	13.27	13.35	1.14	109.26
1901	0.20	0.04	1.81	2.52	15.87	12.01	7.95	17.88	15.91	22.29	21.50	4.87	122.85
1902	1.30	0.35	0.39	5.66	11.30	9.05	12.79	9.45	10.13	11.26	18.66	4.52	94.86
1903	0.20	0.16	0.39	0.47	7.83	10.55	19.69	15.75	8.34	15.51	16.30	20.71	115.90
1904	2.99	0.24	0.59	6.96		18.69	14.49	7.44	14.61	8.38	14.32	3.10	
1905	2.15	0.09	1.60	1.47	18.06	6.84	7.10	13.24	7.70	10.88	4.14	5.54	78.81
1906	0.34	0.18	0.28	4.23	9.67	11.38	19.17	26.10	10.75	8.26	21.38	10.80	122.54
1907	0.09	0.06	0.18	0.23	5.05	13.68	13.29	10.67	11.88	10.29	4.32	1.51	71.85
1908	1.02	0.18	0.24	4.61	19.72	11.06	9.68	16.64	13.45	15.09	10.55	4.02	106.86
1909	2.72	3.71	0.29	3.54	14.32	19.73	13.64	8.15	7.50	19.32	36.22	22.90	152.04
1910	2.99	2.58	2.74	2.99	11.50	13.62	16.99	13.43	18.44	15.37	14.87	15.49	131.01
1911	0.14	2.29	0.01	4.88	16.11	10.53	8.84	10.79	9.29	13.39	13.39	0.39	90.05
1912	0.08	0.33	0.02	0.20	13.43	12.17	10.17	12.87	9.12	13.52	9.62	2.20	83.73
1913	0.96	0.22	0.08	0.72	12.63	11.51	6.99	10.92	8.82	6.41	16.56	1.59	77.41
1914	0.09	0.22	0.05	1.68	5.66	12.55	7.21	12.36	16.98	22.91	7.56	2.25	89.52

TABLE 9.

THE PANAMA CANAL

BOHIO --------- MONTHLY RAINFALL

CHAGRES RIVER VALLEY
(Inches)

Year	January	February	March	April	M a y	June	July	August	Sept	Oct.	Nov.	Dec.	Year
1894													
1895		2.28		9.15	18.40	10.44	4.90	16.81	11.60	16.41	14.97	9.71	
1896	6.80	1.38	0.75	14.97	15.63	8.54	5.55	6.78	15.51	13.35	17.05	----	
1897	2.59	0.00	0.25	8.11	18.54	14.10	15.83	25.20	17.48	26.02	19.57	22.05	169.74
1898	12.36	1.26	3.03	10.59	14.61	19.76	34.96	38.31	13.31	28.23	21.81	6.38	204.61
1899	9.37	4.49	3.28	1.10	10.35	14.80	17.76	12.99	8.90	19.33	10.43	6.18	118.98
1900	7.06	0.48	1.04	2.89	7.42	18.40	17.79	14.02	15.40	18.43	24.98	4.02	131.93
1901	1.61	1.65	2.40	1.81	16.97	12.05	19.68	24.25	24.05	21.06	34.21	11.65	171.39
1902	22.32	0.91	0.96	5.16	13.90	5.55	5.67	8.28	12.48	16.69	13.07	5.24	110.23
1903	3.42	0.24	1.22	3.33	9.74	8.16	10.70	11.04	15.57	13.52	20.91	18.79	116.64
1904	6.88	3.42	3.16	13.72	12.24	8.92	9.54	8.55	12.70	9.21	13.02	5.43	106.79
1905	7.93	0.96	0.43	0.75	18.21	7.71	5.42	15.78	11.22	14.90	13.01	6.43	102.75
1906	0.88	1.94	0.88	5.45	12.09	11.74	17.76	9.02	13.43	9.91	16.99	14.00	114.09
1907	1.60	1.12	1.82	0.59	8.38	15.16	8.70	9.10	13.63	19.00	11.38	2.88	93.36
1908	1.59	1.17	1.77	2.16	18.59	20.02	7.78	20.50	8.74	14.25	19.01	3.40	118.98
1909	7.29	3.74	3.66	7.23	13.69	12.31	11.07	10.01	10.43	16.34	35.39	20.53	151.69
1910	4.02	6.89	6.60	6.46	14.14	11.75	20.82	14.84	16.82	14.53	22.37	21.30	160.54
1911	0.32	1.87	0.97	4.87	12.32	6.96	7.29	5.69	5.30	13.24	17.01	1.34	77.18

Station closed January, 1912.

TABLE 12.

THE PANAMA CANAL

PORTO BELLO --MONTHLY RAINFALL
(ATLANTIC COAST)

Value in Inches.

Year	Jan'y	Feb'y	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Year
1905	---	--	--	--	---	---	--	---	--	--	---	---	--
1906	2.76	1.52	0.93	5.98	---	---	--	---	--	--	---	---	--
1908	--	--	--	--	21.03	16.99	9.98	16.98	8.59	7.28	41.73	25.72	
1909	20.90	6.82	3.56	12.56	9.69	17.70	26.33	13.83	13.99	8.70	45.03	58.17	237.28
1910	14.05	5.89	6.32	7.14	9.30	15.25	22.80	20.71	13.15	9.54	23.08	22.89	170.12
1911	0.84	6.90	2.38	6.60	19.25	18.04	14.48	22.56	17.55	13.78	24.40	2.16	148.94
1912	0.67	1.64	0.60	0.54	16.65	19.77	24.21	14.15	15.03	17.01	25.82	11.52	147.61
1913	5.84	2.03	1.17	2.34	30.51	9.00	20.83	25.35	11.34	18.85	33.47	10.46	171.19
1914	2.38	2.20	.98	2.66	16.22	15.08	7.90	21.30	- - -	- -Station	Closed	- - -	- - -

The diurnal range in temperature is generally greater during the dry season than during the rainy season, and is much greater on the Pacific Coast and in the interior than along the Atlantic Coast.

The average daily range in temperature at the various stations is shown in the following table:

Station	Daily Range—Deg. F. Dry Season	Rainy Season	Years of Record
Ancon	19.1	14.5	8
Culebra	17.2	13.8	7
Colon	6.8	8.9	6

It will be noted that the maximum diurnal range in temperature at Colon occurs in the rainy season, instead of in the

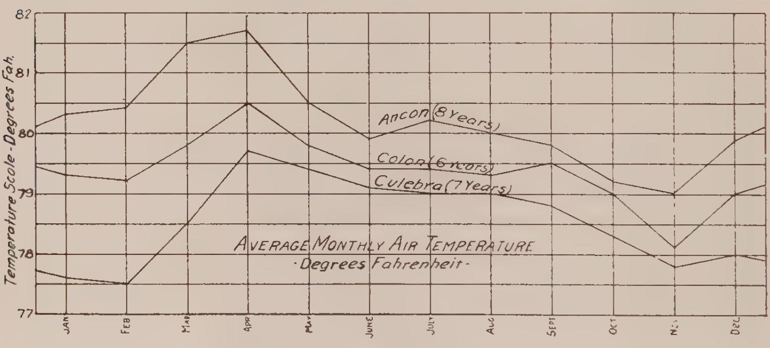

Fig. 4.

dry season, as at the other stations. The explanation of this condition is found in the seasonal variations in the prevailing direction of the winds on the Atlantic side. Air temperatures are much more uniform over water areas than over similarly located land areas. As the winds at Colon blow steadily from off the Caribbean Sea in the dry season, the daily range in temperature is very small, while in the rainy season a large percentage of the winds blow from off the land area to the southward, and a materially wider daily range in temperature is experienced.

Hourly Variations. Figs. 5 and 6 show the average bihourly variations in temperature throughout the day, for both the dry and the rainy seasons. An inspection of these curves

will show that: (1) During the dry season, the daily maximum temperatures occur earlier on the Atlantic Coast than at interior and Pacific Coast stations; (2) in the rainy season the daily maximum occurs at about the same time on both coasts; (3) maximum temperatures occur earlier in the day during the

TABLE 16.

THE PANAMA CANAL
MONTHLY MEAN AIR TEMPERATURE—Deg. Fah.
Mean of daily Max & Min.

ANCON, C. Z. - Elevation of Station 90-ft.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual
1906	81.1	81.8	82.2	83.0	81.9	80.2	80.2	80.2	81.0	79.6	79.4	79.5	80.8
1907	80.2	78.8	81.4	81.2	82.0	80.0	81.0	81.0	80.6	79.6	80.0	81.0	80.6
1908	81.4	81.8	82.6	82.8	80.2	79.9	79.8	80.2	79.6	78.9	78.8	79.6	80.5
1909	79.4	80.3	81.4	81.4	79.4	78.8	78.8	78.7	78.9	78.6	77.0	78.0	79.2
1910	78.8	79.6	79.4	80.4	79.2	79.3	78.3	79.2	78.7	78.5	79.0	79.2	79.1
1911	79.8	79.8	80.0	81.2	79.1	80.0	82.2	80.6	80.8	80.0	79.4	81.0	80.3
1912	80.6	81.3	83.0	82.1	82.0	80.8	80.6	80.2	79.4	79.0	79.0	80.8	80.7
1913	80.8	79.9	82.0	81.6	80.2	80.2	81.1	80.2	79.6	79.5	79.0	80.0	80.3
1914	80.4	81.8	82.9	82.6	81.9	81.0	82.4	81.8	80.3	79.7	80.1	81.2	81.3

CULEBRA, C. Z. - Elevation of Station 385-ft.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual
1907	76.8	75.2	77.8	77.3	79.4	77.8	78.0	78.6	78.6	77.6	78.0	78.0	77.8
1908	77.3	77.4	78.0	80.3	78.8	78.6	78.0	78.6	78.4	77.4	77.4	77.4	78.1
1909	76.8	77.5	78.4	78.9	79.1	78.4	78.7	78.4	78.6	78.5	76.4	76.5	78.0
1910	76.8	77.5	77.4	79.4	78.6	78.9	77.4	78.8	78.6	78.0	77.9	77.4	78.1
1911	77.8	78.0	78.0	80.2	79.2	79.4	80.8	79.8	79.9	78.9	78.6	79.5	79.2
1912	79.0	79.2	80.4	81.4	81.2	80.2	79.8	79.5	78.7	78.6	78.0	78.8	79.6
1913	78.7	78.0	79.8	80.1	79.7	80.1	80.1	79.2	79.1	78.9	78.2	78.5	79.2
1914	78.7	79.6	80.2	82.3	81.4	80.0	81.3	80.4	Station discontinued.				

COLON - Elevation of Station 8-ft.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual
1908	79.5	79.6	79.7	80.1	78.8	79.0	78.3	78.8	79.3	78.7	77.2	77.8	78.9
1909	77.4	78.9	79.3	80.1	79.8	78.7	78.4	78.7	79.1	79.0	76.5	76.6	78.5
1910	77.6	77.8	77.5	79.4	79.0	79.3	77.6	78.4	78.6	78.6	77.8	77.4	78.2
1911	78.3	78.0	78.3	79.6	79.5	79.3	81.1	79.8	80.4	79.4	79.5	82.2	79.6
1912	82.2	80.8	82.4	82.8	82.0	80.2	80.6	80.2	79.4	79.0	78.6	80.4	80.7
1913	80.8	80.0	81.4	80.8	79.4	80.2	80.6	79.8	80.2	79.5	79.2	79.7	80.1
1914	80.7	80.9	81.3	61.4	81.7	80.5	82.0	81.0	79.4	79.8	79.9	81.5	80.8

Temperature records obtained from thermometers exposed in standard instrument shelters from 5-ft to six feet above grass covered ground.

rainy season than in the dry season; (4) the daily minimum temperatures occur around 6 A. M. at all stations during both seasons of the year.

There is no uniformity in the time of occurrence of the daily maxima, as individual records vary greatly. The strongest factor in determining the time of daily maximum tempera-

ture seems to be the degree of local cloudiness during the midday hours, and the direction of prevailing winds with reference to the surrounding land and sea areas.

General H. L. Abbot, U. S. A., retired, discussing the temperature and atmospheric pressure records obtained by the New French Canal Company at Alhajuela and La Boca during the years 1899 to 1904, says:

> "These records show in the most striking manner the extraordinary uniformity of the climate. The absolute extreme range of temperature recorded hourly during the entire period was at Alhajuela from 97.4 degrees F. to

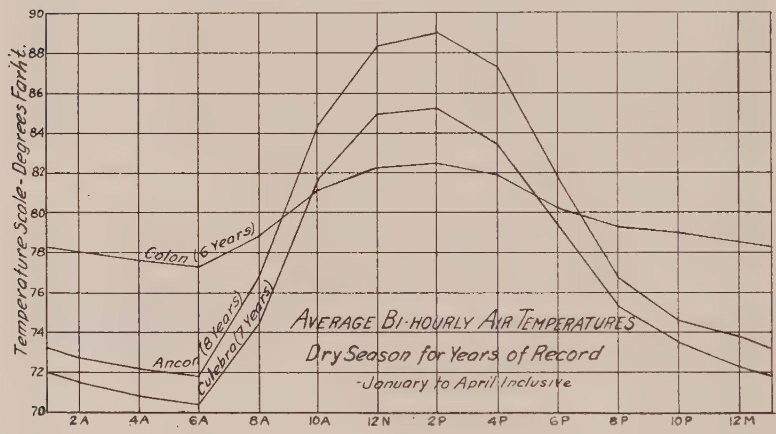

Fig. 5.

> 63.2 degrees F., and at La Boca from 95.2 degrees F. to 68.2 degrees F., both including a normal horary variation of about 13 degrees at the former and 9 degrees at the latter. The barometric extreme oscillation during the same period ranged from 30.04 inches to 29.60 inches, including the normal horary variation of about one-tenth of an inch. All of these extremes occur in the dry season, including February, March and April."

The following table exhibits the temperature extremes of record, and the annual means, at the various stations:

Station	Annual Mean	Maximum Deg. F.	Date	Minimum Deg. F.	Date	Years of Record
La Boca*	79.6	95	April, 1901	68	March, 1900	5
Alhajuela†	79.1	97	April, 1903	63	March, 1903	5
Ancon	80.2	97	April 7, 1912	63	Jan. 27, 1910	9
Culebra	78.6	96	May 5, 1912	59	Feb. 9, 1907	7
Colon	79.3	92	June 3, 1909	66	Dec. 3, 1909	7

It will be noted that both the absolute maximum and minimum temperatures for the year usually occur in the dry season. The comparatively clear sky at this season permits the earth's

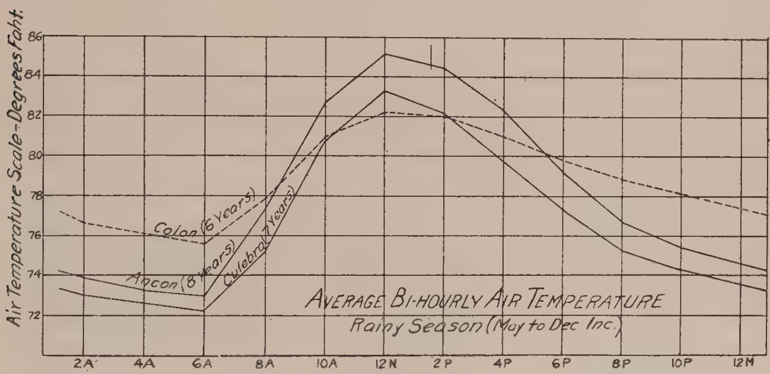

Fig. 6.

surface to receive the maximum amount of solar radiation during the daytime, and to lose the maximum amount of heat at night, by outward radiation.

Winds.

As neither the Panama Railroad Company nor the French Canal kept automatic records of wind movement or direction, the American records obtained since 1905 constitute practically the only Isthmian wind records available. The following discussion is based wholly upon the American records.

The winds along the Atlantic Coast exhibit marked variations between the dry and rainy seasons. During the dry season months fresh northerly trade winds prevail, the wind blowing from the north and northeast 90% of the time, with an

* From French records covering the period from 1900 to 1904.

† From French records covering the period from 1899 to 1903.

average velocity of about 15 miles per hour, while during the rainy season light variable winds prevail, southeast predominating. The average velocity during this season of the year is 8 miles per hour, slightly more than one-half of the dry season velocity.

The prevailing direction of the winds, over the interior and on the Pacific Coast, is from the northwest throughout the entire year, altho the average velocity and the percentage of northwest winds are materially higher in the dry season than during the rainy season months.

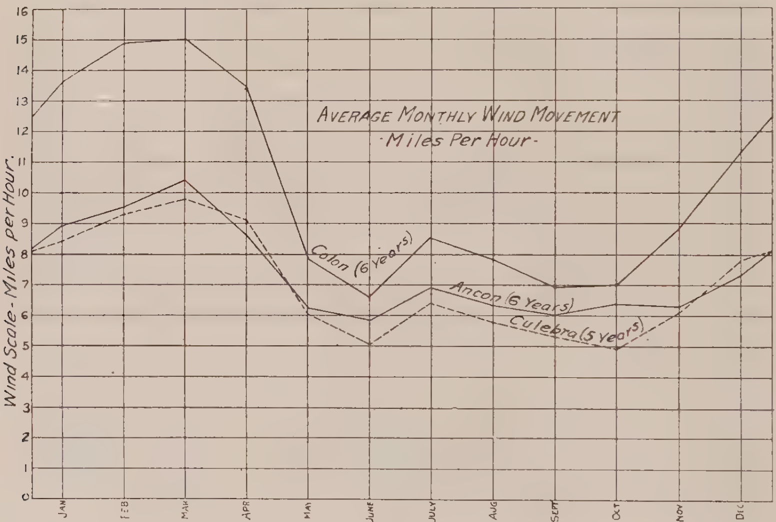

Fig. 7.

Monthly and Hourly Variations. The average monthly wind movement at the various stations is shown in Fig. 7. March is the month of highest average wind movement at all stations, and June and October the months of least wind movement.

Figure 8 shows curves of the average hourly wind movement throughout the day. The average hourly velocity is highest near the hours of maximum temperature, or from 1:00 to 3:00 P. M., and lowest near the hour of minimum temperature, or from 6 to 7 A. M.

Maximum Velocities. The maximum wind velocities of record at the various stations are presented in the following table:

Station	Years of Record	Maximum Wind Velocity (5 min. periods) Miles per Hour	Direction	Date
Sosa	2	50	S	June, 1912
Ancon	7	59	S	July 10, 1909
Culebra	8	40	NE	Nov. 19, 1913
Gatun	4	49	E	August, 1912
Colon	7	40	S	July 16, 1908

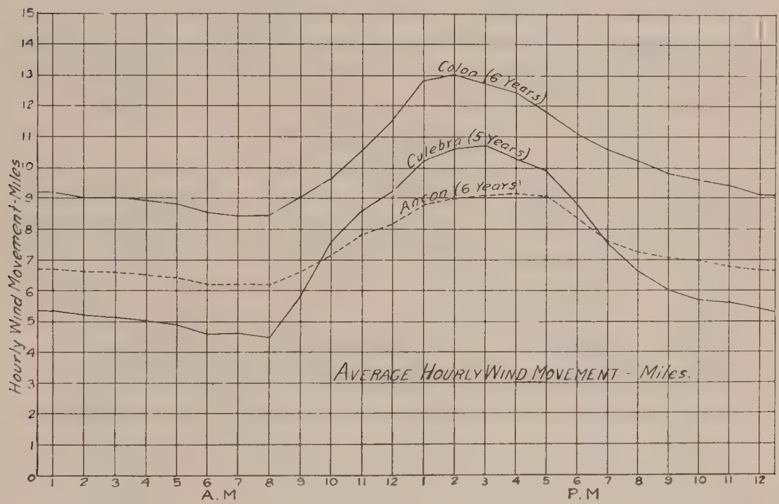

Fig. 8.

From the above table it may be seen that the maximum wind velocity for periods of 5 minutes occurs during the rainy season—the season of least average wind movement. As a rule the maximum wind velocities occur during rain or thunder squalls. These storms are almost invariably of too short duration to cause dangerously rough seas at either canal entrance, although at times they are of sufficient violence to blow down trees, unroof buildings and damage plantations set to bananas or other native plants.

The most severe storms of this character that have oc-

TABLE 17.

THE PANAMA CANAL
AVERAGE WIND MOVEMENT
Miles per hour

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
ANCON - Pacific Coast													
1908	9.2	9.8	9.7	8.7	6.4	6.2	6.9	6.4	5.6	7.1	6.9	6.6	7.5
1909	8.2	9.0	10.3	8.5	5.9	5.7	6.4	5.7	6.3	5.6	6.8	7.6	7.2
1910	8.7	9.9	9.9	8.1	6.3	5.7	6.4	6.1	5.3	7.2	7.0	7.4	7.3
1911	8.7	8.8	9.6	7.9	5.2	5.9	7.7	6.6	6.5	6.4	5.6	8.1	7.2
1912	11.5	11.1	12.0	8.9	6.7	5.7	7.0	6.8	6.2	6.1	7.1	6.7	8.0
1913	7.3	9.3	10.6	9.7	6.7	5.5	6.9	6.2	6.2	5.7	4.2	7.5	7.2
1914	8.1	11.0	11.8	9.0	7.2	6.5	8.1	7.5	6.1	5.9	6.1	6.3	7.8
CULEBRA, C. Z. * Continental Divide													
1909	4.5	4.9	5.4	8.6	5.3	4.8	5.3	4.6	5.0	4.5	6.5	7.5	5.6
1910	8.8	10.3	9.8	8.5	5.8	4.6	5.1	5.6	4.5	5.3	6.6	7.6	6.9
1911	9.9	10.2	10.8	9.0	4.7	5.3	7.9	6.4	6.1	4.7	4.7	8.6	7.4
1912	10.3	11.3	12.0	9.8	7.4	5.2	6.7	6.2	5.5	4.7	7.0	7.5	7.8
1913	8.3	9.7	10.9	9.7	6.6	5.1	7.1	6.2	5.6	5.2	5.8	7.8	7.3
1914	9.0	11.0	11.8	9.3	7.4	5.9	8.3	7.7	Station discontinued.				
COLON - Atlantic Coast													
1908	14.3	16.9	16.6	14.5	6.7	6.7	7.9	6.9	5.4	6.8	8.8	9.6	10.1
1909	11.8	14.1	13.6	12.0	6.3	5.7	6.5	5.5	6.1	6.2	8.5	10.4	8.9
1910	13.6	15.3	13.9	13.1	8.7	6.4	6.8	7.2	5.5	6.6	8.6	11.5	9.8
1911	14.1	15.6	12.9	12.8	5.6	5.8	9.7	8.6	8.9	7.2	7.8	12.4	10.1
1912	14.5	14.5	16.9	14.8	10.2	7.2	10.2	9.3	7.6	7.4	10.4	12.1	11.3
1913	13.5	13.2	16.3	12.9	9.2	7.5	9.8	9.4	7.7	7.6	9.0	11.8	10.7
1914	13.0	15.6	17.2	13.1	11.0	8.2	11.4	10.7	8.7	6.8	7.3	11.0	11.2

NOTES:

* Wind records were obtained at Bas Obispo (in the central section) during the years 1907 and 1908, but these records are not included with the Culebra records as the wind instruments at Bas Obispo had a less favorable exposure.

The wind instruments were exposed at an elevation of 69 feet above the ground at Ancon. When the station was moved to Balboa Heights on October 1, 1914 this elevation was increased to 97 feet.

curred in the Canal Zone since the American occupation are listed below:

Date	Location	Wind Velocity
July 10, 1909	Ancon	59 miles per hour
April 24, 1911	Brazos Brook	Unknown
May 14, 1912	Matachin	60 miles per hour†

Sosa Hill Wind Records. Wind records were obtained in 1912 and 1913 from a station on the summit of Sosa Low, for comparison with the Ancon records. The Sosa Station was established in April, 1912, and discontinued January 1, 1914.

† No wind records were available from any point visited by the storm, so the wind force was estimated from the damage done.

The average wind movement during the year 1913 was 45% greater on Sosa Hill than Ancon, due to the higher elevation and better exposure of the Sosa instruments. The prevailing direction was from the northwest at both stations. Northwest winds prevailed 81% of the time at Sosa and 60% of the time at Ancon.

Wind velocities increase rapidly with increase in elevation above ground. It follows that to render the wind records from adjacent stations strictly comparable, instrument exposures should be similar.

The following comparative table of the monthly wind records at Sosa and Ancon for the year 1913 illustrates the influence of elevation and exposure on the records (distance between stations about two miles):

Month	Average Hourly Velocity Miles		Percent of Northwest Wind	
	Sosa	Ancon	Sosa	Ancon
January	10.7	7.3	89	64
February	13.3	9.3	94	68
March	15.6	10.6	95	77
April	13.5	9.7	88	69
May	9.4	6.7	79	63
June	8.0	5.5	61	43
July	9.3	6.9	91	81
August	8.9	6.2	85	63
September	9.1	6.2	56	36
October	8.3	5.7	63	32
November	8.0	4.2	74	42
December	10.8	7.5	93	80
Year	10.4	7.2	81	60

Fogs.

The duration, character and extent of fog in the Canal Zone have an important bearing on the night navigation of the Canal, the location of range lights, and other aids to navigation, etc. Careful records have been kept of the night and early morning fogginess, at stations located along the line of the Canal.

Practically no fogs occur at either Canal entrance, but night and early morning fogs are numerous at stations in the

interior, especially during the rainy season months. An average of about 200 fogs a year is observed along the Culebra Cut section of the Canal. Most of these occur in the rainy season. Practically all fogs lift or dissipate by 8:30 A. M., so they will not affect the navigation of the Canal during the daytime. A record of the fogs observed along the Canal prism in 1910, an average year, is presented in Table 18.

TABLE 19.

THE PANAMA CANAL
MONTHLY MEAN DAYTIME CLOUDINESS
(Tenths of Sky)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
ANCON, C. Z. - Pacific Coast													
1906	4.8	6.2	5.1	7.7	7.7	8.5	8.9	8.2	8.9	7.8	8.7	8.4	7.6
1907	5.9	5.6	6.2	6.4	8.0	8.9	7.7	8.2	8.7	7.8	6.9	4.7	7.1
1908	3.5	3.6	4.6	5.5	7.3	8.5	7.1	6.9	7.4	7.3	8.1	6.6	6.4
1909	6.0	5.2	5.7	7.1	8.0	8.2	7.5	7.7	7.4	8.0	8.3	7.6	7.2
1910	6.2	6.7	6.4	7.9	8.2	8.5	8.2	7.6	5.5	6.4	6.2	6.4	7.0
1911	4.4	6.9	5.5	8.2	8.0	8.0	6.2	7.5	6.7	7.3	5.0	4.7	6.5
1912	3.8	6.1	5.6	5.1	7.7	7.4	7.8	7.3	7.6	7.5	6.9	5.8	6.6
1913	5.0	3.6	4.4	6.0	8.8	7.4	5.2	6.1	5.5	5.3	5.9	4.3	5.6
1914	3.6	4.0	4.4	5.7	8.0	7.6	6.4	8.2	9.0	8.1	7.5	6.4	6.6
CULEBRA, C. Z. - Continental divide													
1907	5.6	6.5	4.9	6.3	7.4	8.6	8.4	8.2	8.4	8.3	8.0	6.3	7.2
1908	5.7	4.5	6.0	7.3	8.0	8.0	8.2	7.6	8.3	8.3	7.7	6.8	7.2
1909	6.2	5.0	4.1	6.0	6.9	7.6	7.6	6.6	7.1	7.3	8.5	7.6	6.7
1910	5.1	5.3	5.8	7.0	8.1	8.6	8.6	8.1	7.4	7.7	8.1	6.5	7.2
1911	3.8	5.6	4.5	7.5	7.8	8.3	7.0	7.6	7.5	7.4	7.4	4.2	6.6
1912	3.5	4.3	4.1	4.9	7.4	7.8	7.7	7.3	7.5	7.6	7.4	5.2	6.2
1913	4.6	3.7	3.7	5.0	8.0	7.5	8.4	8.9	8.0	8.5	9.2	6.1	6.8
1914	4.9	4.4	4.5	6.3	8.5	8.8	7.9	8.6	Station discontinued.				
COLON, R. P. - Atlantic Coast													
1908	4.4	3.6	4.1	4.7	7.0	6.7	7.1	6.4	7.0	6.8	7.1	5.5	5.9
1909	6.0	4.7	4.8	5.3	6.8	6.2	6.8	6.6	6.3	6.1	7.7	6.9	6.2
1910	5.1	4.6	4.0	6.0	6.8	7.6	8.2	7.1	6.7	6.6	7.8	6.9	6.4
1911	3.9	6.2	3.9	6.6	7.1	7.6	6.4	7.5	6.3	6.7	6.4	5.1	6.1
1912	4.9	5.5	4.4	3.7	6.6	7.3	7.1	6.8	7.0	7.5	8.4	5.3	6.2
1913	4.5	4.0	4.4	5.1	7.1	6.8	7.0	6.9	7.0	6.8	8.2	5.2	6.1
1914	4.6	4.6	4.2	4.8	7.1	7.6	6.5	7.7	8.1	6.9	6.4	5.9	6.2

Cloudiness.

Continuous records of the daytime cloudiness are kept at each first-class meteorological station, but no French records of Isthmian cloudiness are available.

The daytime cloudiness over the Canal Zone is less during the dry season than during the rainy season, the average (in percentage of whole sky observed) being about 52 per cent for the dry season, and 73 per cent for the rainy season.

March is the month of minimum cloudiness, while June has been the month of maximum cloudiness in the Central and Pacific sections, and November along the Atlantic Coast.

The average cloudiness is greater in the interior and over the Pacific section than along the Atlantic Coast. The explanation of this condition is found in the prevailing direction of the winds. During the greater part of the year, the prevailing winds blow from off the Atlantic. These winds reach the Isthmus with water vapor in large measure uncondensed, and

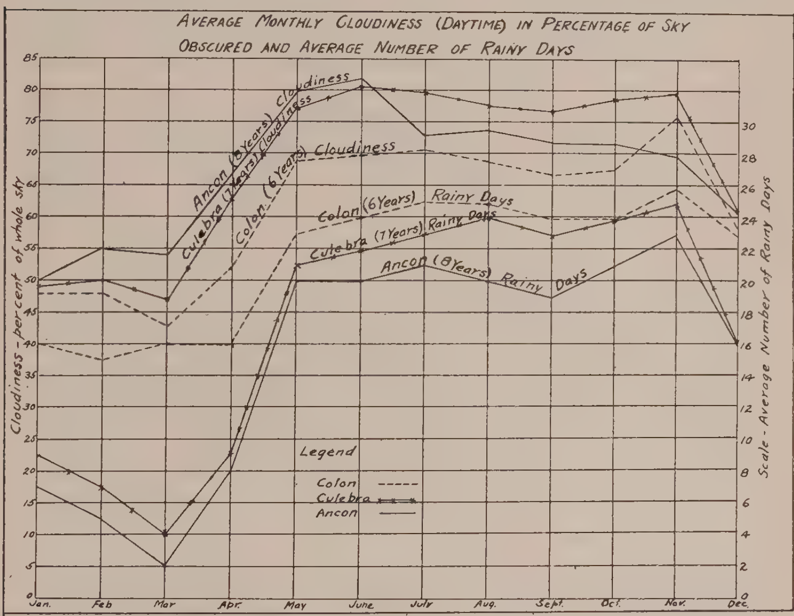

Fig. 10.

therefore not visible in the form of clouds. In crossing the Isthmus a large part of the water vapor carried by the winds is condensed and becomes visible as cloud, the most effective agent of condensation being the convective air currents that develop over the excessively heated land surface, and the upward deflection of the winds in approaching and crossing the continental divide. Any increase in the elevation of a mass of air, from whatever cause, results in a corresponding decrease in its temperature. When the temperature of the ascend-

ing air current is lowered to the dew point, the invisible water vapor condenses and becomes visible as cloud.

The cloudiness is generally greater during the daytime than at night. This is especially noticeable during the dry season, when heavy cumulus clouds form regularly during the daytime, and as regularly disappear with the approach of night.

All of the recognized cloud types are well represented on the Isthmus. Of the lower clouds, the cumulus form are most numerous during the dry season, while strato-cumulus, stratus and nimbus clouds prevail during the rainy season. All of

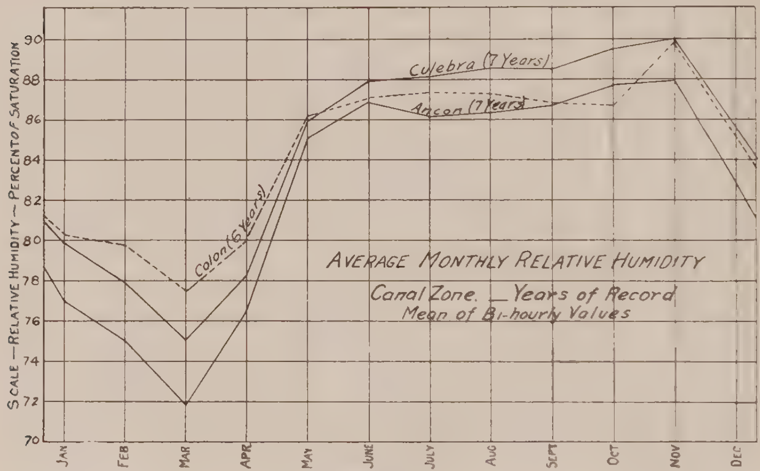

Fig. 11.

the recognized types of upper clouds are well represented throughout the year, altho cirro-stratus and alto-stratus clouds usually predominate, especially in the rainy season. Curves showing the monthly march of average daytime cloudiness are shown in Fig. 10.

Relative Humidity.

November is the month of highest relative humidity in the Canal Zone, and March the month of lowest average humidity. As a rule the relative humidity rises with increase in rainfall, but falls rapidly with rise in temperature. This applies both to the diurnal and the seasonal fluctuations. The regular diurnal fluctuations in relative humidity are greatest in

the dry season, and least in the rainy season. The maximum humidity for the day usually occurs around 6 A. M., and the minimum at about 2 P. M. The absolute range of relative hu-

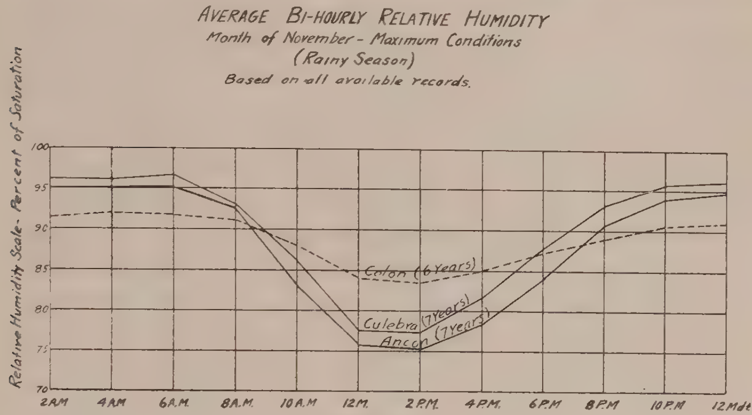

Fig. 12.

midity recorded in the Canal Zone since the American occupation is given below. Absolute maximum, 100%, recorded at various stations a number of times. Absolute minimum, 24%, recorded at Culebra on March 20, 1910.

The average monthly variations in humidity at the three first-class stations are shown on Fig. 11, while Figs. 12 and 13

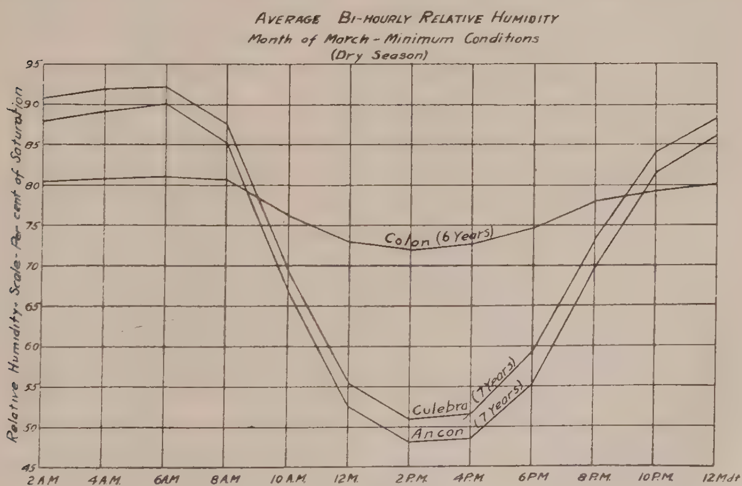

Fig. 13.

show average diurnal humidity curves for the months of maximum and minimum conditions.

Atmospheric Pressure.

The Canal Zone lies within the equatorial belt of low atmospheric pressure and outside the regions of violent atmospheric disturbances. Barometric readings are almost uniform from day to day, changes in pressure are slight, except for the regular well marked diurnal fluctuations characteristic of tropical climates. General storms of wide extent seldom occur in this region. The extensive areas of low pressure and high pressure that cross the continental area of the United States at frequent intervals, producing the cyclonic and anti-cyclonic storms that characterize the climate in middle latitudes, do not extend southward beyond the Tropic of Cancer, and the paths followed by the West Indian hurricanes lie well to the northward of the Canal Zone. It follows that most of the storms on the Isthmus are local rain or thunder squalls of short duration, and do not involve extensive atmospheric disturbances. These local storms are caused by the convective circulation of the air, due to its excessive heating under the influence of solar radiation.

In a region of stable barometric conditions, such as prevail in the Canal Zone, local barometric readings are practically of no value in forecasting weather conditions. Weather forecasts based on local barometric readings may be made, with a considerable degree of success, in regions affected by violent atmospheric disturbances, but a more satisfactory method is to base local forecasts on a study of weather conditions over the entire surrounding territory, as revealed by daily simultaneous weather observations. Daily weather records covering the territory surrounding the Isthmus are not available, and no attempt has been made to forecast weather conditions from day to day, but conditions in the Canal Zone are of such uniformity that fairly accurate forecasts may be made of the general weather probabilities for the various months, based on average conditions.

Northers.

While the Canal Zone lies well south of the paths followed by the destructive West Indian hurricanes, on two oc-

casions since the American occupation the weather on the Isthmus has been affected to a marked degree by the passage of storms of this character across the Caribbean Sea and West Indies.

In October, 1910, the weather on the Isthmus was noticeably affected by the passage of a hurricane of unusual severity over the West Indian and Gulf regions. This abnormal depression over the West Indies and the resulting steep barometric pressure gradient toward the north, caused a general reversal of the wind direction on the Isthmus during the second decade of the month. Brisk southerly winds and generally fair weather prevailed during this period. Heavy rains fell later in the month following the reestablishment of normal atmospheric conditions.

Again in November, 1912, the atmospheric circulation over the Isthmus was affected in a similar manner by the passage of a severe hurricane across the Caribbean Sea and over the island of Jamaica.

Practically the only general storms that visit the section of the Isthmus traversed by the Panama Canal are the so-called ''Northers'', which occasionally extend as far south as the Atlantic entrance to the Canal during the period from October or November to April inclusive. These storms are characterized by steady brisk northerly winds, ranging in velocity up to 30 or more miles per hour, blowing from an anti-cyclonic area of high pressure over the Southern States or Gulf region, toward the equatorial belt of low pressure. They may or may not be accompanied by heavy rainfall. The winds alone are usually of insufficient force to hinder seriously navigation at the Atlantic entrance of the Canal. The principal damage to shipping interests has resulted more often from the heavy swell and high waves that accompany these storms, than from any extremely high maximum wind velocity. The Atlantic entrance breakwaters now protect the inner bay from heavy seas of this character. No marked changes in atmospheric pressure precede these ''Northers'', indicating their approach, but they are accompanied or followed by a considerable rise in pressure.

Altho changes in barometric pressure are very small from month to month, the average pressure is slightly higher in the

dry season than during the rainy season. February has been the month of highest average pressure at all stations, and September the month of lowest pressure.

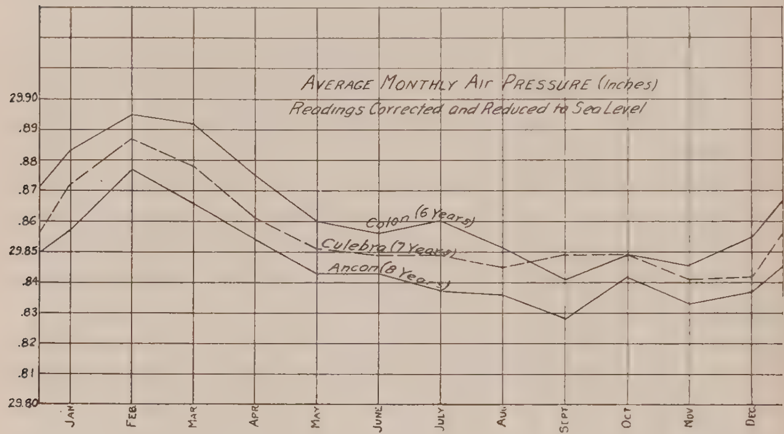

Fig. 14.

Curves of average diurnal pressure fluctuations are exhibited on Fig. 15. These show periods of maximum pressure at about 10 A. M. and 10 P. M., and daily minimum at about 4 A. M. and 4 P. M., with an average diurnal range of about 0.10 inch. Curves of average monthly pressures are shown on Fig. 14.

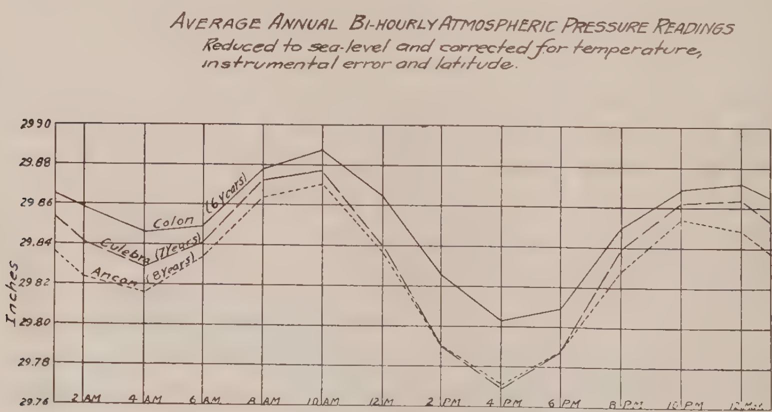

Fig. 15.

TABLE 5.

THE PANAMA CANAL

AVERAGE MONTHLY RAINFALL

VALUES IN INCHES

Station	January	February	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Ancon * (17)	.95	.76	.71	2.72	8.81	8.10	7.76	7.49	7.80	10.53	10.45	4.44	70.52
Balboa (16)	1.04	.51	.73	3.89	7.32	7.86	9.22	7.35	6.98	9.44	9.28	5.92	69.54
Miraflores (6)	1.88	1.52	.60	3.10	10.03	9.74	7.83	8.11	9.91	11.91	11.58	7.51	83.72
Pd. Miguel (7)	1.04	.79	.32	3.17	11.37	10.27	8.50	8.21	8.69	11.64	10.86	6.47	81.33
Rio Grande (10)	1.39	.61	.29	3.01	11.04	9.27	9.98	9.95	10.72	12.01	10.77	5.49	84.53
Culebra (24)	1.68	.55	.65	3.54	11.28	8.83	9.17	10.50	11.20	11.39	12.09	7.28	88.16
Camacho (8)	1.15	.71	.43	3.02	12.31	10.10	9.27	10.15	10.41	12.96	12.58	5.98	89.07
Empire (10)	.79	.54	.36	2.99	10.17	8.61	8.45	9.80	8.51	12.87	10.81	5.15	79.05
Gamboa (32)	1.83	.82	.78	3.40	11.02	9.89	10.18	12.20	10.50	12.58	12.18	6.79	92.17
Juan Mina (4)	.41	.90	.17	1.48	12.09	10.99	8.78	11.63	12.04	13.07	12.44	4.76	88.76
Alhajuela (15)	1.14	.71	.58	2.95	12.24	12.75	12.46	12.90	11.76	13.66	13.97	6.43	101.55
El Vigia (6)	.99	2.08	.60	1.91	11.71	13.95	11.09	12.83	12.78	15.90	15.70	5.59	105.13
Frijoles (3)	1.78	2.46	.26	2.19	15.23	11.67	6.82	12.68	11.36	17.57	14.17	5.77	101.96
Bohio (17)	6.00	2.11	2.01	5.78	13.84	12.14	13.01	14.77	13.53	16.60	19.26	10.67	129.72
Trinidad (7)	3.09	2.46	2.52	4.53	14.53	10.89	8.34	10.68	12.48	14.95	19.28	9.40	113.15
Monte Lirio (7)	3.21	3.69	2.94	4.62	14.20	13.33	11.84	11.85	12.86	16.58	21.66	9.84	126.62
Gatun (10)	3.69	2.32	2.53	4.11	15.33	13.31	11.21	14.20	9.86	16.22	20.76	11.97	125.51
Brazos Brk (8)	3.46	2.37	2.67	3.94	13.88	15.42	15.55	14.94	11.80	16.28	23.42	13.00	136.73
Colon (44)	3.97	1.47	1.63	4.05	12.77	13.38	16.22	15.10	12.52	14.56	21.66	12.10	129.43
Pt. Bello (6)	7.51	4.13	2.49	5.86	17.74	16.12	19.77	18.93	13.28	12.53	30.16	20.63	169.15

Figures in parentheses represent number of years of record.

* Station moved to Balboa Heights, October 1, 1914.

TABLE 10.

THE PANAMA CANAL

GAMBOA — MONTHLY RAINFALL

INTERIOR — INCHES.

Year	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Year
1881						10.63	12.46	9.17	10.39	11.06	12.95	4.76	
1882			0.51	1.50	15.68	6.26	10.12	9.88	11.81	8.15	11.81	1.38	
1883				2.60	9.68	11.02	6.54	15.94	4.13	10.04	7.01	6.30	
1884	0.00	0.71	0.28	6.46	6.18	13.35	9.62	16.50	10.55	22.36	6.18	2.20	94.39
1885	0.20	0.20	0.00	1.38	11.06	10.35	9.06	15.51	16.10	9.33	13.23	11.06	97.48
1886	0.55	1.06	0.71	2.76	15.71	10.55	11.69	16.38	9.13	13.62	16.10	4.61	102.87
1887	2.20	0.08	0.28	6.85	11.02	19.45	14.02	19.17	11.50	14.88	24.06	12.68	136.19
1888	0.12	0.63	0.35	1.26	20.47	11.93	3.27	10.24	12.28	9.57	16.18	16.34	102.64
1889	1.97	4.53	1.42	0.00	4.37	9.10	7.28	10.51	11.42	13.07	8.70	3.35	75.72
1890	4.06	0.35	2.36	3.03	13.27	11.65	10.43	15.35	8.90	21.41	9.92	4.29	105.02
1891	0.63	0.00	0.35	2.13	7.48	9.29	6.06	8.50	10.47	15.71	10.67	6.38	77.67
1892	1.10	0.67	2.56	4.72	16.81	8.54	13.98	14.33	13.74	11.10	10.24	6.58	104.37
1893	0.67	1.06	0.71	7.44	11.89	10.71	15.87	7.95	10.24	16.50	12.57	10.87	116.49
1894	1.46	0.16	0.02	1.34	10.94	9.21	11.43	7.63	15.16	15.85	9.78	7.85	90.83
1895	0.57			5.09	15.37		9.36						
1896				4.55	3.35	2.89	5.54						
1897	0.94	0.20	0.00	3.23	17.44	12.64	9.10	17.20	18.82	12.80	5.91	9.05	107.33
1898	2.76	0.12	0.00	1.42	5.32	4.65	18.43	20.16	4.10	8.70	14.57	2.40	82.63
1899	5.00	1.73	1.34	1.42	8.54	8.78	9.45	10.95	13.46	7.95	8.70	2.68	80.00
1900	1.01	0.16	0.13	3.21	6.76	12.15	13.45	8.92	9.24	12.11	10.67	0.79	78.60
1901	0.35	0.24	0.20	0.79	10.87	7.68	9.21	13.87	8.43	14.14	19.11	6.70	91.59
1902	13.40	0.16	4.37	9.49	10.92	6.30	6.26	8.43	8.90	12.91	14.38	2.24	97.76
1903	0.67	0.12	0.32	0.41	11.35	11.03	13.45	12.87	9.30	14.18	11.94	13.83	99.47
1904	3.35	2.27	1.91	12.00	6.71	9.71	5.01	7.01	12.43	9.51	12.01	4.54	86.46
1905	2.74	0.05	0.41	2.94	10.72	8.59	5.77	11.58	6.65	14.85	5.49	6.68	76.47
1906	1.37	0.47	0.16	6.44	6.22	8.04	17.81	11.33	9.42	5.08	15.92	11.68	94.84
1907	0.28	0.29	0.35	0.44	5.98	9.68	7.92	12.69	14.01	13.02	10.43	2.96	78.05
1908	0.19	0.04	0.50	2.65	15.29	6.15	11.43	11.84	6.28	8.90	7.32	6.92	77.51
1909	2.77	4.07	0.56	5.55	15.37	9.55	11.59	7.03	7.90	16.98	28.41	12.33	122.11
1910	1.24	1.80	3.12	3.85	11.09	12.08	17.00	10.66	12.24	12.90	16.90	13.11	115.99
1911	0.11	0.71	0.38	4.01	14.53	6.98	7.26	7.68	5.20	12.75	10.09	0.97	70.67
1912	0.06	1.11	0.10	0.77	7.94	11.64	14.27	16.64	12.75	13.60	6.56	3.63	89.07
1913	2.65	0.68	0.08	1.07	15.13	8.02	8.06	16.45	9.48	8.71	14.13	1.82	86.28
1914	0.64	0.23	0.02	1.38	10.28	17.78	3.91	7.97	11.50	9.79	7.70	6.15	77.35

TABLE 11.

THE PANAMA CANAL

COLON - MONTHLY RAINFALL ATLANTIC COAST

Values in Inches

Year	January	February	March	April	May	June	July	August	Sept	Oct	Nov	Dec	Year
1863	1.75	2.94	0.85	4.70	15.09	15.32	25.76	10.34	15.54	11.22	17.69	15.21	134.32
1864	1.90	0.77	0.78	0.44	15.87	8.78	16.54	13.37	17.85	12.83	17.90	16.40	123.43
1865	1.10	1.08	0.02	3.89	9.22	16.85	9.61	18.39	8.55	9.69	22.16	5.58	106.14
1866	3.99	1.07	0.21	4.07	14.76	12.17	16.72	12.72	18.82	15.04	21.72	8.42	129.71
1867	1.56	0.80	0.48	1.20	11.88	8.85	16.03	10.82	5.35	20.50			
1868	1.17	2.77	2.18	0.87	7.24	18.11	20.60	12.50	16.16	13.13	21.58	3.72	120.03
1869	0.83	0.73	0.49	5.04	6.72	10.66	18.22	14.02	8.98	14.82	24.13	10.10	114.74
1870	4.30	3.33	4.95	6.46	20.95	12.48	15.60	16.35	6.74	11.21	32.42	14.85	149.64
1871	15.42	0.53	0.05	1.52	1.63	7.70	23.27	11.56	8.00	12.58	12.38	4.94	99.58
1872	5.57	0.75	0.83	1.30	21.43	22.00	19.90	19.97	16.20	30.32	19.11	13.12	168.50
1873	6.33	0.25	0.13	2.18	3.92	13.20	12.50	10.69	10.91	14.30	11.77	0.94	67.12
1874	5.33	1.34	3.94	18.02	8.92	15.87	13.62	17.28	8.22	16.65	20.62	7.89	137.70
1881			1.08	2.52	10.04	15.28	12.24	6.46	6.30	12.91	22.13	10.35	
1882	1.65	1.10	1.69	1.73	13.23	18.90	19.10	13.94	10.63	14.96	22.09	5.08	124.10
1883	1.85	0.47	0.55	1.77	11.85	10.08	13.39	25.43	11.14	16.77	11.10	10.94	115.34
1884	3.39	0.39	0.39	4.33	10.16	10.32	15.59	13.27	9.37	8.66	7.05	3.62	86.54
1885	0.87	0.59	0.55	1.34	7.91	16.61	22.99	20.32	17.44	7.99	24.17	25.51	146.29
1886	2.13	5.00	9.17	1.58	13.15	16.38	11.10	12.20	7.52	14.33	21.89	22.72	137.17
1887	2.01	0.67	0.47	10.63	10.28	16.50	17.05	16.89	15.63	19.61	31.81	13.33	154.88
1889	0.63	1.58	1.26	4.75	8.02	10.15	16.01	11.48	10.70	16.42	25.80	14.72	121.52
1890	7.24	1.02	2.01	2.99	9.76	17.24	10.24	20.51	22.99	21.77	19.49	19.06	154.32
1891	2.52	0.51	1.50	0.51	23.00	7.99	14.02	15.98	17.48	17.48	19.49	4.25	124.73
1892	0.98	2.01	3.98	5.00	18.03	16.97	21.77	15.98	16.26	6.69	26.30	11.30	145.27
1893	1.73	3.82	1.81	8.07	6.58	12.32	11.50	15.12	9.92	12.28	17.80	30.94	131.89
1894	5.35	1.65	0.35	2.16	9.85	12.24	19.10	23.03	18.78	12.40	23.66	25.12	153.69
1895	3.86	1.89	2.09	21.73	16.77	9.25	17.09	14.13	12.09	16.46	20.47	15.71	151.54
1896	4.02	1.30	2.01	9.02	16.46	8.50	13.58	15.51	12.84	13.98	15.63	18.66	131.51
1897	5.42	0.04	0.28	3.74	16.34	18.82	14.06	17.24	17.20	5.83	22.16	18.90	138.03
1898	5.04	0.35	1.58	4.72	12.83	16.38	21.89	10.91	10.24	11.38	12.28	7.95	115.55
1899	6.93	6.49	1.26	0.43	13.90	6.41	27.68	14.80	16.55	15.09	14.49	9.04	133.07
1900	6.06	0.33	1.06	0.75	12.25	11.65	16.81	17.00	9.37	16.33	20.28	4.13	116.02
1901	1.28	0.94	1.67	1.50	6.19	11.05	9.94	12.51	11.88	12.65	32.73	5.41	107.75
1902	19.20	0.59	2.33	4.46	11.10	7.00	16.81	5.78	11.06	14.24	12.18	7.10	111.85
1903	1.00	0.35	0.96	1.65	14.74	10.91	16.73	14.25	11.61	10.04	28.30	15.75	126.29
1904	7.02	0.47	1.65	11.46	11.06	15.83	14.21	11.14	13.86	8.14	26.33	7.02	128.19
1905	8.42	1.13	0.62	2.28	22.96	8.10	9.07	15.01	6.80	13.45	17.92	9.50	115.26
1906	1.47	1.14	1.42	4.23	10.07	14.09	19.23	18.31	12.48	13.34	26.64	15.64	138.06
1907	2.47	1.37	2.16	1.06	6.33	16.89	17.86	18.89	11.72	21.99	15.37	9.36	125.47
1908	3.84	1.08	3.53	1.27	22.49	10.53	14.76	16.89	11.57	10.96	31.72	9.07	137.71
1909	10.61	1.92	1.85	3.56	7.21	17.49	12.83	15.42	16.33	19.31	42.50	34.38	183.41
1910	2.94	3.58	5.46	3.30	12.09	13.63	21.07	14.93	12.05	15.65	30.04	15.20	149.94
1911	0.99	1.81	1.41	3.06	17.13	15.58	14.58	11.60	11.62	16.53	15.81	2.63	112.75
1912	0.28	1.81	0.66	.75	12.03	15.90	13.13	9.87	12.23	17.65	21.81	11.47	117.59
1913	6.71	1.75	0.79	2.69	22.60	11.81	15.13	17.91	9.90	18.63	16.75	6.55	131.22
1914	1.35	1.32	0.91	4.12	17.76	16.30	10.74	16.01	14.80	22.16	18.35	8.88	132.70

TABLE 13.

MONTHLY METEOROLOGICAL DATA, - ANCON, C. Z.

MEANS FOR YEARS OF RECORD (8 YEARS) - 1906 - 1913.

MONTH	Atmospheric Pressure - (Inches.) Sea level - Monthly Mean	Air Temperature — Degs. F. Monthly Mean	Max.	Date	Mean daily Max.	Min.	Date	Mean daily Min.	Mean daily Range	Mean wet Thermometer	Mean Temp. Dew point	Mean Rel. Humidity (1)	Precipitation (In's) Monthly Mean	No. Rainy days	WIND Ave. Hrly Mov.	Prev. Dir.	Max. Velocity Mi. pr hr.	Dir.	Date	No of Days Clear	Pt. Cloudy	Cloudy	Thunder Storm	Average Cloudiness - Tenths of Sky
January	29.857	80.3	93	(2) 1906	89.6	63	(Jan 27) 1910	71.0	18.6	72	71	77	.99	7	8.9	NW	28	NW	Jan. 8 1908	10	18	3	1	6.0
February	29.877	80.4	95	(2) 1908	90.2	66	(2) 1907	70.6	19.6	72	70	75	.81	5	9.6	NW	29	NW	Feb 23 1912	7	16	5	1	5.5
March	29.866	81.5	96	(2) 1908	91.7	65	(2) 1910	71.3	20.4	72	70	72	.76	2	10.4	NW	30	NW	Mch 1 1912	5	22	4	0	5.4
April	29.854	81.7	97	Apr 7 1912	90.6	64	Apr 5 1907	72.7	17.9	74	72	76	2.58	8	8.6	NW	26	N.	Apr 6 1908	2	17	11	5	6.7
May	29.843	80.5	96	(2) 1907	87.7	69	(2) 1910	73.4	14.3	75	74	85	8.93	20	6.2	NW	27	SE	May 28 1910	0	10	21	16	8.0
June	29.843	79.9	95	June 6 1907	86.8	70	(2) 1907	73.0	13.8	75	75	87	8.15	20	5.8	NW	34	S.	June 15 1912	0	8	22	18	8.2
July	29.837	80.2	95	July 23 1907	87.6	67	July 17 1910	72.9	14.7	75	74	86	7.97	21	6.9	NW	59	S.	July 10 1909	2	12	17	16	7.3
August	29.836	80.0	94	(2) 1906	87.4	69	(2) 1908	72.7	14.7	75	74	86	7.57	20	6.3	NW	31	NE	Aug. 19 1910	1	13	17	22	7.4
Sept.	29.828	79.8	93	(2) 1907	86.9	68	(2) 1911	72.8	14.1	75	74	87	7.69	19	6.0	NW	31	NE	Sep. 23 1912	1	14	15	19	7.2
October	29.842	79.2	95	Oct 16 1911	86.2	68	Oct 19 1906	72.2	14.0	75	74	88	10.77	21	6.4	NW	38	SE	Oct. 3 1911	1	13	17	17	7.2
November	29.833	79.0	94	Nov 27 1911	85.9	67	Nov 6 1906	72.0	13.9	74	74	88	10.46	23	6.3	NW	26	SE	Nov. 8 1909	2	13	15	14	7.0
December	29.837	79.9	94	Dec 21 1911	88.2	66	Dec. 3 1909	71.6	16.6	74	73	83	4.22	16	7.3	NW	24	NW	Doc 30 1909	6	15	10	5	6.1
Year	29.846	80.2	97	Apr. 7 1912	88.2	63	Jan 27 1910	72.2	16.0	74.1	73.0	82.4	70.90	182	7.4	NW.	59	S.	July 10 1909	37	171	157	134	6.8

(1) Mean of bi-hourly values. (2) Other dates also.

TABLE 14.

MONTHLY METEOROLOGICAL DATA — CULEBRA, C. Z.

BASED ON ALL AVAILABLE RECORDS (7 YEARS) 1907 - 1913

MONTH	Atmospheric Pressure - Inches - Sea Level - Monthly Mean	Air Temperature - Degs. F. Monthly Mean	Max.	Date	Mean Daily Max.	Min.	Date	Mean Daily Min.	Mean Daily Range	Mean Wet Thermometer	Mean Temp. dew point	Mean Rel Humidity (1)	Precipitation -Inches- Monthly Mean (2)	Number Rainy Days	Wind Average Hourly Mov. (5 yrs)	Prev. Dir.	Maximum Velocity Mi. per hr.	Dir.	Date	Number of Days Clear	Pt. Cloudy.	Cloudy	Thunder Storm	Average Cloudiness - Tenths of Sky
January	29.872	77.6	90	Jan. 8 1912(2)	85.7	60	Jan 31 1907	69.7	16.0	72	70	80	1.74	9	8.4	NW	30	N	Jany 31 1910	9	18	4	1	4.9
February	29.887	77.5	91	Feb 10 1912	86.3	59	Feb. 9 1907	69.0	17.3	71	69	78	.57	7	9.3	NW	33	N	1910 & 1911	7	17	4	1	5.0
March	29.878	78.5	93	Mch 30 1909	87.6	61	Mch 30 1907(2)	69.7	17.9	71	69	75	.68	4	9.8	NW	35	N	Mch 4 1912	10	15	6	0	4.7
April	29.866	79.7	96	Apr 17 1912	88.6	62	Apr 1 1907	71.0	17.6	73	71	78	3.67	9	9.1	NW	31	N	1909 & 1911	3	16	11	3	6.3
May	29.851	79.4	96	May 5 1912	86.6	68	May 27 1907(2)	72.2	14.4	74	73	86	11.18	21	6.0	NW	28	NE	May 25 1909	0	12	19	17	7.7
June	29.849	79.1	92	June 6 1910(2)	85.9	67	June 29 1907	72.2	13.7	74	74	88	8.87	22	5.0	NW	31	S	June 11 1913	0	8	22	20	8.1
July	29.849	79.0	92	July 20 1911	85.8	67	July 21 1909(2)	72.1	13.7	74	73	88	9.34	23	6.4	NE	39	N	July 20 1910	0	9	22	20	8.0
August	29.845	79.0	92	Aug 8 1912(2)	86.0	68	Aug 4 1908(2)	72.0	14.0	74	74	89	10.54	24	5.8	NW	40	NE	Aug 27 1913	1	10	20	21	7.8
Sept.	29.837	78.8	91	Sep 17 1909(2)	85.9	67	Sep 24 1912	71.8	14.1	74	73	88	11.20	23	5.3	NW	32	NE	Sep 23 1912	0	12	18	19	7.7
Oct.	29.849	78.3	92	Oct 16 1911	85.2	66	Oct 26 1908	71.4	13.8	73	73	89	11.32	24	4.9	NW	35	S	Oct. 3 1911	0	10	21	19	7.9
Nov.	29.841	77.8	90	Nov 10 1908	84.0	67	Nov 28 1907	71.6	12.4	73	73	90	12.26	25	6.1	NW	40	NE	Nov 19 1913	0	8	22	12	8.0
Dec.	29.843	78.0	92	Dec 21 1911	85.3	64	Dec 11 1908	70.7	14.6	73	72	86	7.41	16	7.8	NW	27	NE	Dec 28 1911	5	16	10	4	6.1
Year ----	29.856	78.6	96	May 5 1912	86.1	59	FEB 9 1907	71.1	15.0	73.0	72.1	84.6	88.78	207	7.0	NW	40	NE	Nov 19 1913	35	151	179	137	6.9

(1) Mean of bi-hourly values. (2) Other dates also.

TABLE 15.

MONTHLY METEOROLOGICAL DATA — COLON, R. P.

BASED ON ALL AVAILABLE RECORDS (6 YEARS) - 1908 - 1913.

MONTH	Atmospheric Pressure - Inches - Sea Level - Monthly Mean	Air Temperature - Degs. F. Monthly Mean	Max.	Date	Mean Daily Max.	Min.	Date	Mean Daily Min.	Mean Daily Range	Mean Wet Thermometer.	Mean Temp- Dew Point	Mean Rel. Humidity (1)	Precipitation (Inches) Monthly Mean	Number Rainy Days.	Wind Average Hourly Velocity	Prev. Dir.	Maximum Velocity Mi pr hour	Dir.	Date	Number of Days Clear	Pt. Cloudy	Cloudy	Thunder Storms	Average Cloudiness Tenths of Sky
January	29.883	79.3	88	Jan 22 1912	82.7	70	Jan 24 1909(2)	75.9	6.8	74	73	80	4.03	16	13.6	N-NE	32	N	Jan 28 1909(2)	9	18	4	1	4.8
February	29.895	79.2	88	Feb 27 1912	82.5	71	Feb. 3 1910(2)	75.9	6.6	74	72	80	1.48	15	14.9	N-NE	36	NE	Feb 14 1910	9	16	3	0	4.8
March	29.892	79.8	88	Mch 29 1912	83.2	67	Mch. 2 1910	76.4	6.8	74	72	77	1.65	16	15.0	N	36	NE	Mch 17 1913	13	16	2	0	4.3
April	29.875	80.5	90	Apr 20 1912	84.0	72	Apr 14 1909	76.9	7.1	75	73	80	4.05	16	13.4	N	33	NE	Apr 24 1912	8	16	6	2	5.2
May	29.860	79.8	91	May 5 1912	84.3	71	May 15 1908(2)	75.1	9.2	76	75	86	12.65	23	7.8	N	36	N	May 19 1908	2	16	13	13	6.9
June	29.856	79.4	92	June 3 1909	84.2	70	June 17 1909	74.8	9.4	76	75	87	13.32	24	6.6	SE	33	SE	June 1 1909	2	15	13	18	7.0
July	29.860	79.4	89	July 27 1912	83.5	70	July 16 1908(2)	75.3	8.2	76	75	87	16.35	25	8.5	N-SE	40	S	July 16 1908	2	15	14	17	7.1
August	29.851	79.3	89	Aug 9 1912	83.6	71	Aug 8 1909	75.0	8.6	76	75	87	15.08	25	7.8	SE-W	30	S	Aug 7 1908	2	17	12	16	6.9
Sept.	29.841	79.5	90	Sep 10 1908(2)	84.4	71	Sep 12 1909(2)	74.6	9.8	76	75	87	12.47	24	6.9	SE	37	W	Sep 2 1912	3	13	14	17	6.7
Oct.	29.849	79.0	90	Oct 6 1908(2)	84.1	70	Oct 26 1908(2)	73.9	10.2	75	74	87	14.38	24	7.0	SE	38	SW	Oct 23 1912	3	15	13	14	6.8
Nov.	29.846	78.1	89	Nov 27 1911	82.3	69	Nov 29 1909	74.0	8.3	75	74	89	21.74	26	8.8	W	39	SW	Nov 22 1909	1	13	16	10	7.6
Dec.	29.855	79.0	89	Dec 1 1911	82.8	66	Dec 3 1909	75.2	7.6	75	74	85	12.18	23	11.3	N	38	N	Dec 3 1910	7	16	8	4	5.8
Year	29.864	79.3	92	June 3 1909	83.5	66	Dec 3 1909	75.2	8.3	75.3	74.0	84.4	129.38	287	10.1	N	40	S	July 16 1908	61	186	118	112	6.2

(1) Mean of bi-hourly values. (2) Other dates also.

TABLE 18.

THE PANAMA CANAL

FOGS ALONG THE CANAL PRISM, YEAR 1910.

	ANCON			PEDRO MIGUEL			CULEBRA			BAS OBISPO		
Months	No.	Duration H.m	Mean time commenced	No.	Duration H.m.	Mean time commenced	No.	Duration H.m.	Mean time commenced	No.	Duration H.m.	Mean time commenced
Jan'ry	1	5:00	3:30 am	--	--	--	7	33:10	1:38 am	9	37:30	1:43 am
Feb'ry	-	--	--	--	--	--	5	12:00	4:16 am	4	11:30	4:30 am
March	-	--	--	2	3:15	4:30 am	9	19:15	3:16 am	8	38:30	2:30 am
April	-	--	--	4	7:05	3:10 am	10	25:35	2:52 am	13	56:10	1:34 am
May	-	--	--	8	24:15	3:49 am	23	109:35	2:35 am	29	117:15	1:48 am
June	-	--	--	11	30:25	3:44 am	17	107:00	12:37 am	24	132:25	12:41 am
July	-	--	--	9	33:35	3:17 am	25	148:00	1:10 am	10	45:30	1:45 am
August	1	7:00	3:30 am	8	16:10	4:28 am	22	122:45	11:47 pm	23	93:05	2:02 am
Sept.	1	1:30	5:00 am	22	71:15	2:14 am	23	160:40	10:35 pm	26	132:25	1:34 am
Oct.	1	1:30	6:00 am	26	105:45	1:36 am	22	159:50	10:43 pm	26	127:00	12:20 am
Nov.	3	4:00	5:20 am	25	119:45	1:00 am	15	91:45	1:04 am	16	59:05	2:36 am
Dec.	1	2:00	4:30 am	15	59:55	1:19 am	19	118:45	12:24 am	13	43:00	3:03 am
Total -	8	21:00	----	130	471:25	----	197	1108:20	-----	201	893:25	----
Mean -		2:38	4:38 am		3:38	2:55 am		5:37	1:15 am		4:27	2:00 am

	BOHIO			GATUN			CRISTOBAL		
Months	No.	Duration H.m.	Mean time commenced	No.	Duration H.m.	Mean time commenced	No.	Duration H.m.	Mean time commenced
Jan'ry	13	62:00	2:45 am	7	17:45	3:13 am	--	---	---
Feb'ry	4	15:00	2:38 am	1	1:30	2:30 am	--	---	---
March	5	20:10	3:18 am	1	4:00	Midnight	--	---	---
April	9	23:50	4:00 am	3	21:30	Midnight	2	7:55	3:27 am
May	19	69:25	3:19 am	4	10:35	2:41 am	2	6:45	3:22 am
June	26	141:20	12:59 am	11	28:53	3:10 am	--	---	---
July	24	104:20	2:20 am	13	51:20	2:33 am	--	---	---
August	24	152 30	12:45 am	11	32:39	2:11 am	1	7:00	3:30 am
Sept.	24	171·05	11:52 pm	19	51:35	1:08 am	--	---	---
Oct.	24	177:50	11:17 pm	15	51:45	2:06 am	--	---	---
Nov.	20	115.00	12:15 am	10	25:45	2:16 am	1	3:30	4:00 am
Dec.	25	158:00	11:35 pm	8	26:50	2:07 am	--	---	---
Total -	217	1210:30	-----	103	324:07	----	6	25:10	-----
Mean -		5:35	1:36 am		3:09	1:55 am		4:12	3:35 am

PERCENTAGE OF FOG DISSIPATED

	ANCON	PEDRO MIGUEL	CULEBRA	BAS OBISPO	BOHIO	GATUN	CRISTOBAL
Before 6:30 am	50	67	41	56	45	85	17
Before 7:30 am	100	98	75	90	88	99	83
Before 8:30 am	100	100	98	95	100	100	100

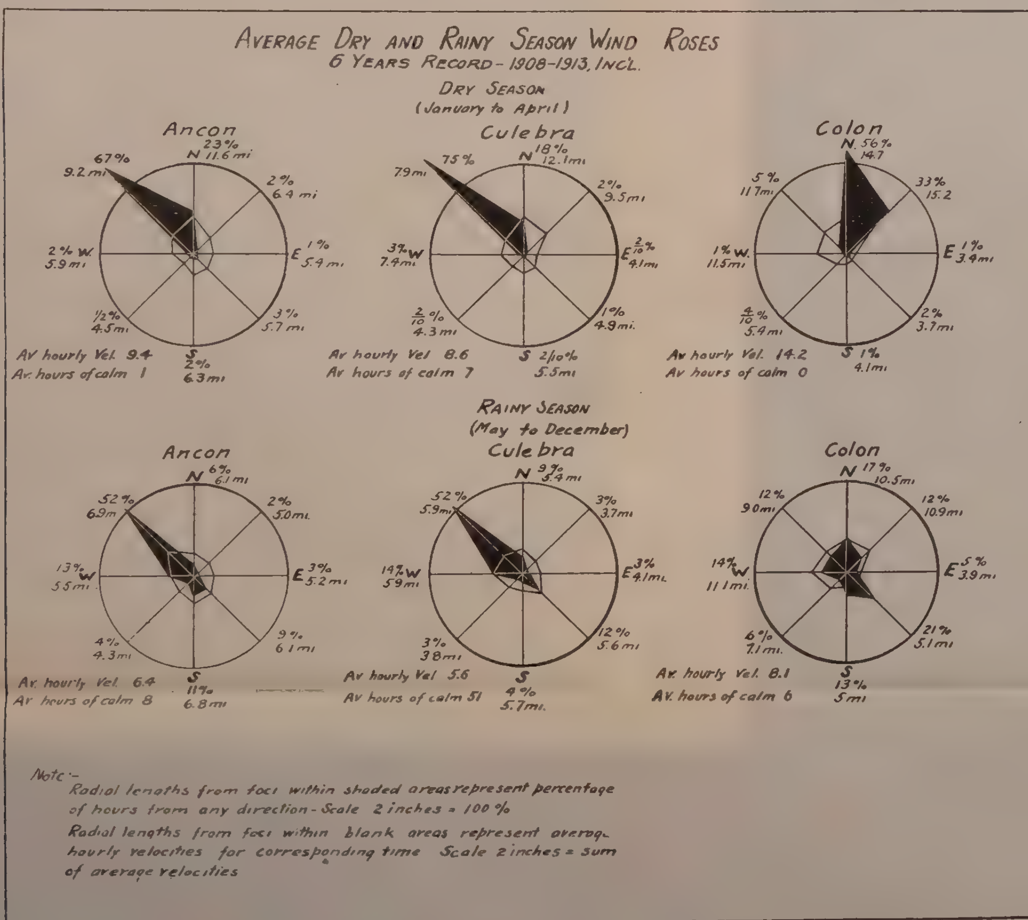

Fig. 9.

TABLE 21.

THE PANAMA CANAL
MONTHLY EVAPORATION RECORDS - CANAL ZONE
VALUE IN INCHES.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
BAS OBISPO													
1907	5.175	5.072	6.538	6.486	4.661	3.125	3.152	3.582	3.358	2.938	3.599	4.896	52.602
1908	5.617	5.729	6.290	5.475	3.175	3.415	3.250	3.425	3.635	3.875	2.730	3.445	50.061
Average 2 years	5.396	5.400	6.414	5.980	3.928	3.270	3.201	3.504	3.496	3.406	3.164	4.170	51.329
ANCON, C.Z.													
1908	3.348	6.557	6.997	5.921	3.219	3.046	3.017	3.203	3.049	3.256	2.414	2.942	46.969
1909	3.348	3.728	4.931	3.883	2.451	1.916	2.080	2.271	2.484	2.826	2.332	3.020	35.270
1910	4.354	5.350	6.190	4.379	3.378	2.666	2.740	2.866	3.078	3.436	3.132	3.528	45.097
1911	6.024	4.530	6.485	4.163	2.949	2.812	3.869	3.117	3.595	3.595	3.181	5.300	49.620
1912	7.370	6.755	7.795	5.721	3.746	3.098	3.386	3.648	3.395	3.458	3.723	5.333	57.428
1913	5.935	6.439	7.816	6.465	3.963	3.615	3.858	3.908	4.006	4.169	3.379	4.700	58.253
Average 6 years	5.063	5.560	6.702	5.089	3.284	2.859	3.158	3.169	3.268	3.457	3.027	4.137	48.773
RIO GRANDE													
1909				5.960	4.205	3.417	3.117	3.353	3.768	3.094	2.713	2.993	
1910	4.612	5.529	6.003	3.986	3.916	2.654	2.846	3.096	3.677	3.577	2.999	3.442	46.337
1911	5.940	4.912	7.462	5.139	4.015	3.646	4.989	4.564	4.096	3.924	3.055	5.344	57.086
1912	6.363	6.134	7.099	6.732	5.350	3.836	3.908	3.983	3.335	3.763	3.275	4.723	58.501
1913	5.372	5.844	6.762	6.456	4.033	3.812	3.963	3.901	3.783	3.758	2.741	4.525	54.950
1914	5.520	5.965	7.062	6.413	4.870	3.733	5.084	4.520	Station closed.				
Average 5 years	5.565	5.677	6.878	5.651	4.304	3.473	3.765	3.779	3.732	3.623	2.957	4.205	53.609
BRAZOS BROOK													
1909				5.366	4.597	3.806	3.042	3.760	4.169	4.168	2.152	2.379,	
1910	4.622	4.668	6.151	5.025	4.304	3.516	3.014	3.189	3.804	4.177	2.718	2.746	47.934
1911	6.293	5.115	6.872	4.939	3.280	2.917	4.358	4.066	4.101	3.937	3.364	5.176	54.428
1912	6.066	5.572	7.081	7.321	5.707	3.729	4.425	4.611	4.487	3.970	3.100	4.860	60.929
1913	6.397	6.616	8.455	7.466	4.167	4.500	4.277	4.248	4.934	4.343	3.071	4.747	63.211
1914	6.331	6.456	7.769	Station closed.									
Average 5 years	5.940	5.685	7.266	6.023	4.413	3.694	3.823	3.975	4.299	4.119	2.881	3.982	56.100
GATUN													
1911						2.799	4.560	4.407	4.583	3.609	2.661	5.376	
1912	7.208	6.048	7.649	7.394	5.335	3.263	3.889	4.316	3.799	4.123	3.351	4.809	61.184
1913	5.435	6.889	8.602	7.333	4.606	5.083.	4.664	4.570	4.934	4.844	3.560	4.291	64.811
1914	4.821	6.298	7.504	6.688	5.262	4.558	5.520	4.684	4.074	4.233	4.180	5.083	62.905
Average 3 years	5.821	6.412	7.918	7.138	5.068	3.715	4.371	4.431	4.439	4.192	3.197	4.825	61.527
COLON													
1908	4.868	7.958	7.557	6.930	2.570	3.184	2.822	3.192	3.327	3.324	2.700	4.056	52.488
1909	4.868	5.353	6.445	6.468	3.868	2.498	2.445	2.636	2.727	3.027	1.950	2.746	45.031
1910	5.257	4.574	6.500	5.209	3.493	2.703	2.359	2.852	2.791	3.343	2.817	3.732	45.630
1911	8.165	7.104	9.085	5.399	3.296	2.950							
1912				6.055	4.842	3.162	3.512	3.639	3.787	3.812	3.558	4.860	
1913	5.993	5.915	7.702	7.179	3.731	3.414	3.370	3.129	3.555	3.328	3.000	4.626	54.942
1914	6.125	5.974	6.519	5.643	4.020	3.394	4.400	3.725	3.469	3.605	3.856	5.044	55.774
Average 5-1/2 Yrs.	5.879	6.146	7.301	6.207	3.633	2.985	2.902	3.090	3.237	3.367	2.805	4.004	51.556

Note: Insulated tanks 10 inches in diameter at Ancon and Colon. Water surface protected from sun and rain.
Exposed concrete tank 12-1/2 feet in diameter at Bas Obispo.
Exposed pans 4 feet in diameter and 10 inches deep floating in water at Rio Grande, Brazos Brook and Gatun.
Water surface 4 inches below top of pan.

The means and extremes in atmospheric pressure at the various stations are presented in the following table:

Stations	Annual Means	Sea Level Pressure—Inches Maximum	Date	Minimum	Date
Alhajuela*	29.830	30.044	Feb. 1900	29.604	Apr. 1903
Ancon	29.846	30.020	Feb. 17, 1906	29.628	Dec. 19, 1911
Culebra	29.856	30.021	Mar. 18, 1910	29.642	Dec. 19, 1911
Colon	29.864	30.029	Feb. 23, 1911	29.654	Dec. 19, 1911

TABLE 20.

THE PANAMA CANAL

AVERAGE MONTHLY ATMOSPHERIC PRESSURE - INCHES

Readings reduced to sea level and corrected for Temperature, Instrumental Errors, and Latitude
Mean of 8 A.M. and 8 P.M. Readings

ANCON - Pacific Coast (1)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1906	.845	.900	.885	.850	.840	.845	.830	.845	.840	.860	.835	.885	29.855
1907	.887	.918	.886	.890	.848	.836	.839	.839	.822	.852	.842	.826	29.857
1908	.878	.876	.864	.846	.854	.856	.861	.850	.846	.846	.848	.842	29.856
1909	.853	.868	.821	.862	.847	.854	.854	.862	.844	.838	.845	.842	29.849
1910	.864	.872	.884	.844	.864	.844	.850	.842	.836	.852	.830	.856	29.853
1911	.858	.850	.905	.827	.835	.834	.819	.806	.806	.828	.824	.789	29.832
1912	.838	.858	.844	.865	.828	.837	.823	.824	.822	.830	.831	.818	29.835
1913	.844	.870	.847	.846	.838	.828	.830	.816	.814	.836	.803	.840	29.834
1914	.871	.852	.852	.830	.808	.808	.794	.802	.820	.854	.849	.818	29.830

CULEBRA - Continental Divide * (2)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1907	.880	.920	.890	.900	.860	.840	.840	.850	.830	.860	.850	.840	29.860
1908	.895	.900	.883	.864	.864	.868	.878	.869	.864	.857	.862	.859	29.872
1909	.876	.884	.840	.877	.853	.862	.867	.868	.848	.846	.854	.854	29.861
1910	.878	.886	.900	.856	.874	.852	.856	.850	.844	.858	.838	.865	29.863
1911	.869	.861	.919	.838	.839	.838	.829	.816	.817	.837	.830	.802	29.841
1912	.851	.874	.854	.874	.840	.848	.832	.836	.834	.844	.842	.828	29.846
1913	.856	.867	.863	.856	.850	.837	.844	.828	.822	.844	.813	.850	29.846
1914	.878	.869	.878	.856	.834	.828	.821	.830	Station closed.				

COLON - Atlantic Coast

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1908	.902	.908	.893	.871	.862	.862	.876	.866	.856	.846	.860	.856	29.872
1909	.874	.890	.844	.881	.852	.858	.864	.868	.845	.842	.848	.861	29.861
1910	.887	.897	.910	.866	.878	.853	.861	.856	.846	.856	.844	.877	29.869
1911	.887	.876	.935	.853	.847	.848	.842	.825	.822	.844	.840	.814	29.853
1912	.872	.892	.882	.897	.854	.860	.852	.846	.840	.846	.850	.845	29.861
1913	.875	.908	.890	.884	.870	.854	.868	.846	.838	.858	.831	.876	29.866
1914	.907	.890	.898	.869	.843	.835	.834	.839	.834	.854	.850	.822	29.856

(1) Station moved to Balboa Heights on October 1, 1914.
(2) Bas Obispo records from January 1907 to May 1909.
(3) Base number 29.00 inches.

* French records for years 1900 to 1904. Note extremes at Alhajuela are from hourly readings, while extremes at remaining stations are taken from 8 A. M. and 8 P. M. observations.

Evaporation.

Evaporation is the process by which aqueous vapor is taken up from water surfaces and returned to the atmosphere. The water vapor in the air is derived primarily from the large ocean areas. It is carried about and distributed over the earth's surface by the prevailing winds. Condensation and precipitation complete the "meteorological cycle", and return the water to the earth's surface again, in the form of rain or snow.

The laws of evaporation are complex and not thoroughly understood, but the principal factors influencing the rate of evaporation are wind movement, temperature and vapor pressure. In a region of equable temperature conditions, such as prevail in the Canal Zone, wind movement and vapor pressure are of paramount importance in affecting the rate of evaporation.

As the success of the lock type of Canal depends largely upon an adequate water supply, it will be seen that the rate of evaporation from the surface of Gatun Lake, especially during the dry season, has an important bearing on the successful operation of the Canal. In recent years valuable evaporation data have been collected at stations located at Bas Obispo, Rio Grande and Brazos Brook reservoirs and on Gatun Lake, and from rain-sheltered insulated tanks at Ancon and Cristobal. These records are discussed below.

Equipment.

The equipment at each station consists of a copper pan four feet in diameter and ten inches deep, floating in an open section of the lake or reservoir. An anemometer for recording the wind movement, a thermometer for registering the water temperature, and a rain gage complete the instrumental equipment. The evaporation pan is protected from wave action by a light wooden frame properly buoyed. In locating these evaporation stations, the aim has been to obtain conditions within and surrounding the pan as nearly as possible approximating the conditions that prevail over the lake surface. The water level in the pans is maintained at approximately 4 inches below the top. Readings are taken daily, due allowance being made for any rainfall that may have occurred since the previous reading.

Records. The rate of evaporation is much higher during the dry season than in the rainy season. Weather conditions in the dry season favor a high rate of evaporation. The high wind movement, low humidity and vapor pressure, light cloudiness and high daytime temperature, all tend to accelerate the rate of evaporation. The quantity of water lost from the sur-

Fig. 16. Evaporation Pan, Gatun, 1914.

face of Gatun Lake by evaporation during the four dry season months is nearly as great as the quantity lost during the eight months of the rainy season. Fig. 17 shows the relation between the rainfall and evaporation over the surface of Gatun Lake, while Table 21 gives the monthly evaporation records at the various stations. It will be noted that the total evaporation for the year usually ranges between 50 inches and 60 inches.

TABLE 22.

THE PANAMA CANAL
EVAPORATION IN CANAL ZONE

Comparative Values for Day and Night.

Value in Inches.

Month	1908*						1909			
	Ancon		Bas Obispo		Cristobal		Ancon		Cristobal	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
January	.....	......	.....	......	......	......	1.755	1.593	2.754	2.114
February	5.062	1.495	3.605	2.124	4.200	3.758	2.134	1.594	2.916	2.437
March	5.566	1.431	3.919	2.371	4.402	3.155	2.693	2.238	3.660	2.785
April	4.404	1.517	3.630	1.845	3.999	2.931	2.108	1.775	3.594	2.873
May	2.001	1.218	1.715	1.460	1.706	0.864	1.317	1.134	2.268	1.600
June	2.034	1.012	1.955	1.460	1.878	1.306	0.941	0.975	1.332	1.166
July	1.900	1.117	1.670	1.580	1.584	1.238	1.078	1.002	1.252	1.193
August	2.175	1.028	1.702	1.723	1.985	1.207	1.241	1.030	1.467	1.169
September	1.924	1.125	2.178	1.457	2.096	1.231	1.425	1.059	1.706	1.021
October	2.051	1.205	2.467	1.408	2.016	1.308	1.862	0.964	1.784	1.243
November	1.362	1.052	1.555	1.175	1.572	1.128	1.395	0.937	1.129	0.821
December	1.337	1.605	2.040	1.405	2.252	1.804	1.775	1.245	1.484	1.262
Total	29.816	13.805	26.436	18.008	27.690	19.930	19.724	15.546	25.346	19.684
Per cent	68%	32%	60%	40%	58%	42%	56%	44%	56%	44%

* 11 months 1908.
** Readings taken at 8:00 A.M. and 8:00 P.M. daily.

Exposed concrete tank 12-1/2 feet in diameter at Bas Obispo
Insulated tanks 10 inches in diameter at Ancon and Cristobal.

Comparative records of the night and day evaporation are presented in Table 22. A higher rate of evaporation prevails during the daytime than at night. About 60% of the total evaporation occurs during the daytime (8 A. M. to 8 P. M.) and 40% at night.

Three floating evaporation pans were installed on Gatun Lake in May, 1911, for the purpose of determining the rela-

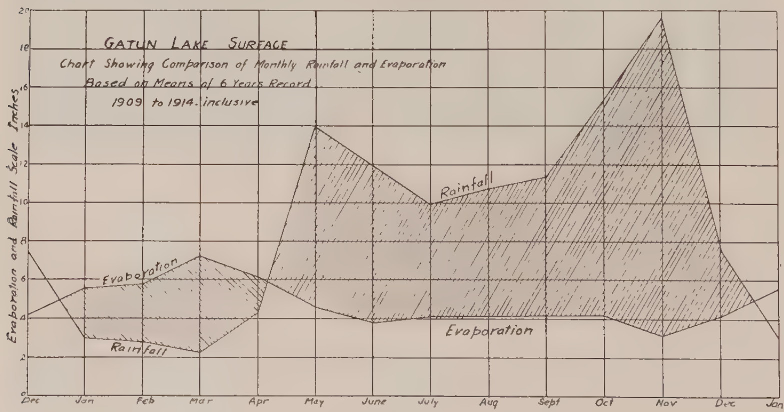

Fig. 17.

tive rates of evaporation over the open sections of the lake and along the grass and timber covered margins. One pan was anchored south of the Spillway, well out in the open section of the lake. The second pan was located in the timber fringe bordering the south shore of the lake, and the third in the middle of a grassy marsh toward the south shore. Records were continued during a period of six months. The evaporation from the pan in the open section of the lake was found to exceed materially the evaporation from the pan located along the lake margin. The differences were least during the months of heavy rainfall and light wind movement, and greatest during the months of light rainfall and stronger winds. The average evaporation from the pan located in the fringe of timber bordering the lake amounted to 72%, while the evaporation from the pan in the marsh was 75% of the evaporation from the exposed pan.

The higher rate of evaporation over the open section of the lake is due principally to greater wind movement, which keeps the air in circulation and prevents the accumulation of a protecting vapor blanket directly overlying the water surface, altho the freer exposure to the sun's rays is a factor in increasing the rate of evaporation from open sections of the lake.

The monthly records from each of these stations are shown in the following table:

Gatun Lake Evaporation Records.

1911	Station No. 1		Station No. 2		Station No. 3	
	Wind Mov. miles	Evapor. inches	Wind Mov. miles	Evapor. inches	Wind Mov. miles	Evapor. inches
May	3.9	2.12	1.5	1.75	......	1.83
June	3.9	2.80	1.0	2.41	......	2.48
July	5.9	4.56	1.5	3.28	......	2.78
August	4.7	4.41	0.9	3.07	......	3.37
September	5.0	4.58	1.0	2.63	......	3.13
October	4.1	3.61	0.7	2.77	......	3.00
Means	4.6	3.68	1.1	2.65	......	2.76

Note: Station No. 1—Open section of lake, evaporation..............100%
" No. 2—Timber fringe, evaporation.......................... 72%
" No. 3—Marsh, evaporation 75%

The wind movement is expressed in miles per hour. In estimating the loss of water from Gatun Lake by evaporation,

the rate of evaporation from the open section of the lake is applied to the whole lake area. The figures are probably high, but the error is on the safe side.

Sea Temperature.

Continuous automatic records of the surface temperature of the sea water at both Canal entrances have been obtained since January, 1908. The average annual sea temperature is about 82 degrees F. on the Atlantic Coast, and 80 degrees F. on the Pacific side. In general, sea temperatures average higher in the rainy season than in the dry season. The absolute range on the Atlantic Coast is small, about 12 degrees F., while on the Pacific side the range is relatively large. The highest sea temperature recorded at Balboa during the past seven years was 89 degrees F., and the lowest 60 degrees F., the absolute range for this period being 29 degrees F.

On the Pacific Coast, the lowest sea temperatures occur in February and March, and the highest in August or September. The sudden drop in sea temperature in the dry season is due, in part at least, to the convective ocean currents that develop at this season of the year under the influence of the fresh northerly winds. The steady, fresh, off-shore winds blow the warm surface water out to sea, while the return deep-sea current, that completes this convective circulation, carries the cold water from lower level to the surface close inshore.

The means and extremes in sea temperature on the two coasts are presented in the following table:

Station	Maximum	Date	Minimum	Date	Annual Mean
Balboa	89	August, 1909	60	February, 1910	79.9
Colon	87	Several dates	75	Several dates	81.9

Temperatures in degrees F.

Miscellaneous Phenomena.

Thunderstorms. Thunderstorms occur frequently on the Isthmus during the rainy season months, but seldom in the dry season. The average number of thunder storms observed during the year, is about 135 in the interior and on the Pacific Coast, and 115 on the Atlantic side. August is usually the month of maximum frequency, with an average of about 20 thunderstorms during the month, while March is the month of

minimum frequency, with practically no thunderstorms. Most of these storms occur during the afternoon hours, few at night. Compared with conditions over the eastern half of the United States, thunderstorms are of much more frequent occurrence on the Isthmus, though not particularly more severe than storms of the same character in the States. In the United States a larger percentage of the thunderstorms occur at night.

Hail. Hail has been observed in the Canal Zone or vicinity three times since observations were begun in 1906, as follows:

Naos Island, June 15, 1912, during a heavy rain squall; at Alhajuela on the afternoon of May 28, 1910, and at Cucaracha in 1908, exact date unknown. On the dates mentioned, the hail stones that fell were small and melted quickly, and in no case was the fall excessive.

The phenomenon is unusual in a low-lying tropical country, but severe hailstorms are experienced frequently at high altitudes in mountainous regions within the tropics.

Halos and Corona. Lunar halos and corona are observed occasionally near the time of full moon when light conditions are favorable. Solar halos also occur at times when the sky is overcast with a thin film of hazy cloud. But few solar corona are observed in this region.

Water Spouts. Water spouts have been observed at both Canal entrances. They usually precede or accompany rain squalls. The spouts observed have not been numerous, and are mentioned only as interesting meteorological phenomena.

TIDES.

Pacific Coast.

Available tide records at or near the Pacific entrance to the Canal cover the following periods: Naos Island 1882-1887 (French records), and 1906-1907 (American records), and continuous automatic records at Balboa from July, 1907, to January, 1915.

The average tidal range on the Pacific side for consecutive tides is about 12.5 ft., while the maximum spring range occasionally exceeds 20 ft. The average monthly tide levels are highest in the rainy season, October or November, and low-

est in the dry season, February or March, as the steady, fresh, off-shore winds, during the dry season, tend to depress the water level.

Table 23 shows the average range of spring and mean tides, and the average tide level on the Pacific Coast, based on 5 years' records.

Atlantic Coast.

Tidal records at Colon cover the periods from 1882-1887 (French records), and from July, 1907, to January, 1915 (American records).

Tidal fluctuations need not be considered in navigating the Atlantic entrance to the Canal, as the average tidal range is only about 0.9 ft., and the extreme range approximately 2 ft. Typical tide curves for the Atlantic and Pacific Coasts are shown on Fig. 18. Assuming the correctness of the precise levels run across the Isthmus by Walhecht & Thomas, mean sea level on the Pacific Coast, based on available records, is approximately 0.6 ft. higher than mean sea level on the Atlantic side.

The tidal extremes of record at Balboa and Colon are given below. Table revised to January 1, 1915, elevations referred to mean sea level:

Station	Max. High Water		Extreme Low Water		Max. Daily Range		Min. Daily Range*	
	Feet	Date	Feet	Date	Feet	Date	Feet	Date
Balboa	11.2	Oct. 2, 1909	10.6	Apr. 11, 1910	20.8	Apr. 11, 1910	5.1	Mar. 24, 1911
Colon	1.65	Nov. 27, 1909	1.01	June 9, 1910	2.17	June 28, 1911	†	

SEISMOLOGY.

The Panama Canal is located outside the destructive earthquake belt, but it lies sufficiently close to regions of violent seismic activity, in Costa Rica and Nicaragua, to render the study of Isthmian seismology of peculiar interest and importance.

Local history since the Spanish settlement of the country, and the state of preservation of certain ancient ruins that date from the earliest European settlement, support the belief that

* For consecutive tides.

† One tidal fluctuation often entirely absent at Colon.

the area comprised in the Canal Zone has not been visited by violently destructive earthquakes in modern times.

The best available records show twenty-eight earthquakes prior to 1904, of which only one can be classed as destructive, being that of September 7, 1882; although some writers claim that a destructive earthquake occurred in 1621, which destroyed nearly all the houses in Panama. In Mendosa's his-

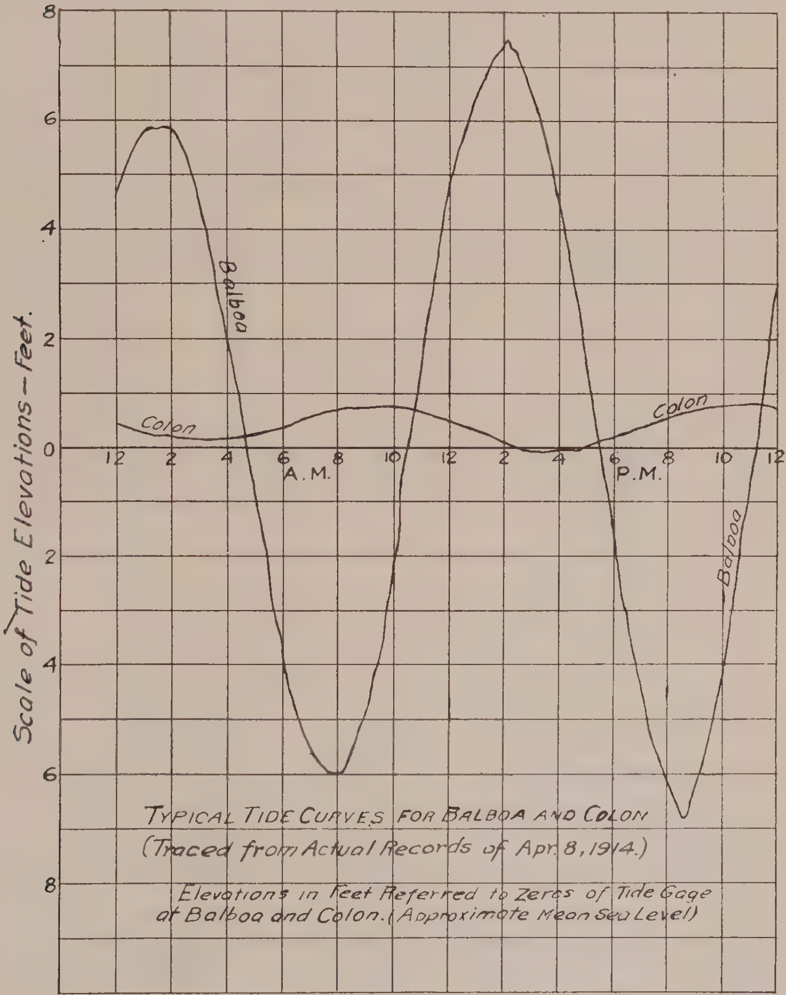

Fig. 18.

tory, the foundation of Old Panama is given as August 18, 1519, and, in speaking of the city, he mentions that it contained eleven streets, three squares, one cathedral, two hermitages, five convents, one hospital, several royal houses, one municipal house and one tribunal. The total number of houses was 504, and of these only eight were masonry, three hundred and thirty-two wood, and the rest native huts. In this history Mendosa describes the great fire that occurred in 1644, when

TABLE 23.

THE PANAMA CANAL

BALBOA SPRING AND NEAP TIDES

Means of 5 years' records
1909 to 1913 Inclusive

	Mean Spring Tides		Mean Neap Tides		
Month	High Water	Low Water	High Water	Low Water	Mean Tide Level*
Jan.	+7.9	-7.6	+4.5	-4.3	+.442
Feb.	+8.2	-8.3	+3.8	-4.0	+.134
Mar.	+8.3	-8.7	+3.7	-3.7	+.094
Apr.	+8.3	-8.4	+4.0	-3.6	+.264
May	+8.0	-7.3	+4.9	-3.7	+.732
June	+7.8	-6.9	+5.5	-3.9	+.879
July	+8.1	-6.9	+5.2	-3.9	+.897
Aug.	+8.7	-7.4	+4.7	-3.4	+.879
Sept.	+9.2	-7.6	+4.6	-2.9	+.984
Oct.	+9.4	-7.7	+4.5	-2.8	+1.083
Nov.	+8.5	-7.2	+4.9	-3.4	+1.044
Dec.	+8.0	-6.9	+5.2	-3.8	+.918
Year	+8.37	-7.57	+4.62	-3.61	+.696

* From hourly elevations.

Elevations in feet referred to Zero of Balboa gage staff

most of the town was destroyed, including the cathedral, but no mention is made of an earthquake having destroyed the city in 1621, just twenty-three years before the great fire. These details are given with the object of showing that there is considerable information about that epoch, and that if a catastrophe of such magnitude occurred, it would surely have been mentioned in one of the most authentic histories of the time.

The "Star and Herald", dated September 14, 1882, gives a résumé of the news of the week, in which it says that the cathedral in Panama suffered, but only to a limited extent, as

TABLE 24.

THE PANAMA CANAL

LIST OF SENSIBLE EARTHQUAKE SHOCKS

ANCON, C. Z.

Covering period from 1909 to 1914 inclusive.

GREENWICH MEAN TIME

Date	Max. Amplitude of Record (mm)	Estimated Intensity Rossi-Forel Scale	Approximate distance of epicenter (Miles)
Aug. 30, 1909	54 plus (1)	III	Near - Direction S. W.
Jan. 1, 1910	35	II	Epicenter probably in vicinity of Martinique.
May 5, 1910	38	II	Destructive Cartago earthquake.
Sept. 24, 1910	42	III	Local shock.
Dec. 20, 1910	55	III	225 miles.
Dec. 21, 1910	75 plus (1)	IV	225 miles.
Apr. 10, 1911	55 plus (1)	III	100 miles.
Apr. 17, 1912	68 plus (1)	III	225 miles.
Apr. 6, 1913	40	II	100 miles.
Oct. 1, 1913	75 plus (1)	V	115 miles,- S. W.
Oct. 1, 1913	?	III	115 miles,- S. W.
Oct. 4, 1913	75 plus (1)	IV	115 miles,- S. W.
Oct. 12, 1913	45 plus (1)	III	115 miles,- S. W.
Oct. 23, 1913	?	IV	115 miles,- S. W.
Nov. 15, 1913	75 plus (1)	III	115 miles,- S. W.
Feb. 7, 1914	57	III	115 miles,- S. W.
Feb. 10, 1914	75 plus (1)	IV	115 miles,- S. W.
Apr. 20, 1914	35 plus (1)	II	250 miles,-
May 28, 1914	75 plus (1)	VI	100 miles,- S. W.

(1) Record incomplete - pens thrown from sheets.

Records are from Bosch-Omori 100 K. seismographs - magnification 10 - damping medium. Period of pendulum 25 seconds. The amplitude indicates half of the complete range of maximum motion. Omori's formula used in computing distances.

it was a piece of isolated wall that fell. Cracks opened in several buildings, and part of the old municipal house fell. This, however, was a very old building poorly constructed. There was also some slight damage done along the line of the Panama Railroad. In appreciating the extent of the disturbance, due consideration should be given to the character of

the structures involved. There is no doubt that this earthquake was the most pronounced of any of which there is record on the Isthmus. The automatic tide register at Colon showed a tidal wave of small amplitude at the time of the earthquake.

A similar record was made by the mareograph at Naos on January 31st, 1906, when the amplitude of the wave exceeded three feet, and the disturbance continued for several hours with diminishing displacement.

In December, 1908, two 100 K and two 25 K Bosch-Omori seismographs of the most improved types were installed at Ancon. Continuous seismological records have been obtained since this date. The instruments are of sufficient sensitiveness to record not only local shocks, but the faint tremor from severe earthquakes, no matter how far distant the point of origin. Tremors from destructive quakes in Mexico, Alaska, Russian Turkestan, Chile and other distant regions have been recorded by the Ancon instruments.

Most of the disturbances recorded have been either slight shocks of nearby origin (less than 200 miles distant), or faint tremors from shocks of distant origin. During the six years period from 1909 to 1914, inclusive, about 20 shocks occurred that were of sufficient intensity to be felt generally over the Isthmus, ranging from intensity II to VI on the Rossi-Forel scale. A list of these shocks is presented in Table 24.

The number of earthquakes recorded at Ancon by months is shown in Table 25. The average number of shocks recorded per year has been 45. October and February have been the months of maximum earthquake frequency, and January and March the months of minimum frequency. However, averages of this character are thought to have little value when based on records covering a period of no longer duration than six years.

Seismic disturbances were more numerous and more severe on the Isthmus during the fiscal year 1913-1914 than in any previous year since the American occupation of the Canal Zone. Eighty-seven shocks were recorded at Ancon during this period. Of these, 55* were of comparatively local origin, less than 200

* Possibly 56.

miles distant. The remainder were tremors from shocks of distant origin.

Practically all of the local shocks seemed to originate in the vicinity of the lower coast of Los Santos Province, approximately 115 miles southwest of Ancon. Ten of these shocks were of sufficient intensity to be generally felt over the Isthmus, ranging up to intensity V or VI on the Rossi-Forel scale. The Canal works suffered practically no damage from these disturbances, although the new Administration building at Balboa Heights was damaged slightly by the shock of May 28th, 1914.

Waves were produced on Gatun Lake by the earthquake of May 28, 1914, the automatic registers showing a movement of 0.3 feet at Gatun, 0.1 foot at Pedro Miguel and 0.2 feet at Miraflores Lake. The general direction of the waves was from the southwest, the epicenter of the shock being located about 115 miles southwest of Panama. The Miraflores register is located at the north end of Miraflores Lake, and the Gatun register at the north end of Gatun Lake, which accounts for the larger amplitude registered at these stations, whereas Pedro Miguel register is at the extreme south end of Gatun Lake.

A list of earthquake records at Panama, obtained by the New French Canal Company, is exhibited below, abstracted from Abbot's Problems of the Panama Canal:

Panama Earthquake Records.

Month	1900	1901	1902	1903	1904
January	....	0	0	0	1
February	....	0	0	0	1
March	....	0	0	0	0
April	....	0	2	1	0
May	....	0	0	0	....
June	....	0	0	0	....
July	....	0	0	0	....
August	....	0	0	0	....
September	1	4	0	0	....
October	0	1	0	0	....
November	0	0	0	0	....
December	0	0	0	0	....
Years	1	5	2	1	2

Of the 11 shocks recorded during this period, 7 were classed as (light) tremors, and 4 as light shocks. The French records listed above are not strictly comparable with the later American records, as modern seismographs are far more sensitive than the instruments used by the French Canal Company, and record many slight tremors that would not affect the less sensitive instruments.

TABLE 25.

THE PANAMA CANAL

MONTHLY RECORD OF EARTHQUAKES RECORDED AT ANCON, C.Z. FOR PERIOD 1909 - 1914. BOSCH-OMORI SEISMOGRAPHS.

Month	1909	1910	1911	1912	1913	1914	Average.
Jan.	0	5 (1)	2	0	1	2	2
Feb.	2	3	1	2	1	22 (2)	5
Mar.	1	1	0	3	4	3	2
Apr.	0	6	3 (1)	4 (1)	3	2 (1)	3
May	5	7 (1)	3	2	1	4 (1)	4
June	1	2	6	2	3	0	2
July	12	2	2	6	3	0	4
Aug.	12 (1)	2	3	0	6 (1)	1	4
Sept.	16	3 (1)	2	0	1	1	4
Oct.	9	1	4	0	39 (5)	1	9
Nov.	5	1	2	6	2 (1)	2	3
Dec.	2	3 (2)	7	2	3	0	3
Year	65 (1)	36 (5)	35 (1)	27 (1)	67 (7)	38 (4)	45 (19)

Note: Figures in parenthesis indicate number of shocks of sufficient intensity to be felt locally.

HYDROLOGY.

The Chagres River.

As the Panama Canal for more than half its length follows the valley of the Chagres, the magnitude of the river's flood discharge is important in relation to the works necessary for controlling and discharging the surplus water, without injuring the Canal or obstructing navigation.

The river is formed by two streams, one named the Chagres and the other the Pequeni, which join at a point in the hills called "Dos Bocas", about 55 miles from the sea, measured by the sinuous route the stream has made for itself.

The Chagres proper has its headwaters among the mountains of the Cordillera de San Blas, about 45 miles above Dos Bocas, where there are mountain peaks from 2000 to 4000 feet above sea level, from some of which the Caribbean Sea can be seen, about fifteen miles to the north.

Although nearly the entire country, from its headwaters to Alhajuela, is clothed with vegetation, much of which is dense,

Fig. 19. Chagres River, View near Las Hornos, showing effect of flood water on limestone banks.

the slopes are so precipitous, and the rock lies so near to the surface, that severe tropical rain storms convert the precipitous banks of the Chagres into a series of small torrents and cascades, causing the river to rise suddenly and discharge almost inconceivable volumes of water. It is this feature that lends importance to the study of the floods of the Chagres.

The general direction of the river from its source to the Rio Indio, about 5 miles above Dos Bocas, is southeasterly, thence to Dos Bocas it is nearly due east. Descending the river, numerous rapids are encountered, and two canyons, each about one mile

in length, separated by a series of rapids about one-half mile in length. Just below the last canyon are two water-falls, about 500 feet apart, each having a fall of about 7 to 8 feet. These falls are about five miles above where the Rio Indio joins the Chagres. To this point the river has passed through a formation of granite, hard trap and basalt. At the Rio Indio, limestone formation is encountered, and continues until the village of Tranquilla is reached, two miles above Dos Bocas. At Tranquilla the scenery changes; the river enters an open plain, which extends six or seven miles to the foothills in the east, and down stream for four miles to Vigia, and from Dos Bocas up the Pequeni for about eight miles. At Dos Bocas the river banks are only a few feet above the surface of the river at ordinary stages.

The Pequeni has its source in the Continental Divide about thirty miles from Dos Bocas, and eight miles from the coast of the Caribbean Sea near Nombre de Dios.

Its course is nearly due south to Dos Bocas. Before it is joined by the Boqueron, at a point about nine miles above Dos Bocas, its course lies through a section of country wild and picturesque, resembling in part the main features of the upper Chagres, but lacking in velocity and volume.

The Pequeni ordinarily discharges at Dos Bocas about one-half as much water as is brought down to this point by the Chagres.

From Dos Bocas to Vigia, about one mile, the river flows through an open plane of several miles in extent towards the east. At Vigia the elevation of the river bottom is +125 feet above sea level. The scenery here changes; instead of open stretches of country sloping down from distant foothills, as in the vicinity of Dos Bocas, the banks of the river are solid masses of limestone, rising abruptly from the river bed to elevations varying from 100 to 300 feet. The stream is sinuous; in some places the convex curve has undermined the limestone, forming overhanging ledges and caverns of considerable size.

The scenery is everywhere one of entrancing beauty and infinite variety until Alhajuela is reached, where the elevation of the river bottom is + 92 above mean sea level.

Descending the river from Alhajuela to Gamboa, about 11

miles, thirty rapids are encountered (this refers to conditions before the waters of Gatun Lake were impounded), and the water flows bright and sparkling, except during the times of freshets or floods. About one-half mile above Gamboa the last outcroppings of limestone are noticed, and the numerous small rivulets or mountain streams that contributed their mite to the volume of the river have disappeared.

At Gamboa the elevation of the river bottom is + 42 feet above mean sea level, representing a slope of over four feet to the mile from Alhajuela. Here the river makes a sharp turn to the right and at the same time changes its character from a swift running river to a slow flowing muddy stream.

From Gamboa the river meanders through a narrow valley, varying from one-quarter to one mile in width, until Bohio is reached, where the elevation of the river bottom is — 3 feet. The effect of the tide is plainly discernible here during low water stages. The district below Bohio drained by the Chagres consists mainly of low hills and swamps, which extend for about 10 miles up the Trinidad and about 4 miles up the Gatun. These swamps serve as a storage basin and regulator of flood waters, permitting them to run off gradually.

This area, covered as it was by luxuriant vegetation and timber, required a large amount of water. Likewise, the loss by evaporation from these conditions during the dry season was considerable.

The increased loss by evaporation from the surface of the lake after the disappearance of the timber is, it is believed, more than offset by the increase in direct rainfall on the lake surface and the swamp water which was formerly lost to runoff before the elevation of the lake exceeded the elevation of the swamps.

Borings have been made in the valley of the Chagres from Alhajuela to Gatun, with a view of determining the character of the earth and depth of the rock. It is found that at Alhajuela there is a depth of about 29 feet of gravel overlying the rock in the bottom of the stream. At Gamboa, just above the junction of the Obispo, the gravel covering the rock bed is about 50 feet in depth. At San Pablo the bed of gravel, sand, etc., is about 90 feet in thickness; at Bohio, the rock is about 150 feet below the tide level, and the drills penetrated wood at

various depths to 150 feet. At Gatun, the depth to what has been classed as rock, and indurated sandy clay, is 258 feet. Here, also, buried wood was brought up by the drills. It seems, therefore, to be certain that what may be called the rock bottom of the geological valley of the Chagres is represented by a deep groove or channel, now entirely or partly filled by the products of erosion and drift. If there has been a regional subsidence of the Isthmus, which the geologists suggest as possible, it may be that the ancient Chagres discharged into the sea through an ancient valley, which, with the land adjacent thereto, was some 300 feet higher in relation to the ocean than the present valley.

The Trinidad and Gatun Rivers.

The Trinidad River is the largest tributary of the Chagres River below Dos Bocas. It has its headwaters in the continental divide, about nine miles from the Pacific Coast. It has an extreme length of over fifty miles, and flows nearly due south, entering the Chagres about four miles south of Gatun. At about forty miles from its source it is joined by a branch, which is the larger, and is called the Siri Grande. The drainage area of the two streams is long and narrow, the streams running about parallel from their sources to where they unite to form the Trinidad. From this point to the Chagres the Trinidad flows through a low swamp for about ten miles, the surface of the river being only two or three feet below the surface of the swamp at ordinary stages of the river. It has a drainage area of 314 square miles, and a mean discharge of 1376 cubic feet per second. The maximum discharge of record is 4280 cubic feet per second, December, 1909, and the minimum is 67 cubic feet per second, April 25, 1908. At the headwaters of the Trinidad the ridges are low, only a few isolated peaks exceeding 1000 feet in elevation.

The Gatun River enters the Chagres about one mile south of Gatun. It has an extreme length of about thirty-five miles. For a distance of about thirty miles the river flows through a comparatively hilly country, with many rapids marking its course. The lower portion, for a distance of about five miles, flows through a low, flat country resembling that of the Trinidad. It has a drainage area of 127 square miles, and a mean discharge of 827 cubic feet per second. The maximum discharge

of record is 7640 cubic feet per second, December, 1909, and the minimum is 27 cubic feet per second, April 3, 1908. Its source is among the hills in the northwesterly part of the basin, where the top hills are from 2000 to 2800 feet above mean sea level.

The Caño.

The Caño River enters the Chagres from the southwest, about fifteen miles above Gatun. The drainage area for a few miles above its mouth is low and flat, after which its bed rises rapidly. Drainage area, 52 square miles.

The Obispo.

The Obispo River originally entered the Chagres a little below Gamboa. It is now cut by the Canal and the main portion of the flow is diverted into the Chagres at Gamboa. Drainage area, 37 square miles.

The Chilibre.

The Chilibre River enters the Chagres from the east about six miles above Gamboa. Its lower portion runs through a comparatively flat country, but rises gradually until its source is reached among the central hills. Drainage area, 54 square miles.

At each of the regular gaging stations established, the following data are available:

1st. Description of Station;
2nd. List of Discharge Measurements;
3rd. Gage Height Table;
4th. Rating Curve;
5th. Table of estimated monthly and yearly discharge and run-off.

The description of the station gives, as far as possible, such general information about the location and equipment as will identify the station. It also contains, as far as possible, a complete list of all changes which have occurred since the establishment of the station, and which affect the use of the data collected.

The discharge measurement table gives the results of the discharge measurements made during the year. This includes the data, the hydrographer's name, the gage height and discharge in second-feet.

The table of daily gage heights gives for each day the fluc-

tuations of the surface of the river, as found from the bi-hourly readings recorded by the automatic register.

The rating table gives the discharge in second-feet corresponding to each stage of the river, as given by the gage height. It depends upon the general law that for streams of practically constant cross section the discharge is a function of the gage height, and that like gage heights have the same discharge.

In the preparation of this table the discharge measurements were plotted on cross-section paper to some convenient scale, using the gage heights as ordinates and the discharges as abscissae. Through these points a smooth curve was drawn, which is the basis for the table. From this curve was tabulated, on forms prepared for the purpose, the discharge corresponding to each tenth of a foot on the gage. The first and second differences between the successive discharges were then taken. These were adjusted on the assumption that there is a gradual increase in the discharge as the gage height increases, and the discharge values in the table were then adjusted according to these revised differences. In preparing the rating table all available data were brought into use, including special conditions which might affect the discharge. For high waters, above the stage covered by discharge measurements, the curve was extended by a tangent line. In case the river overflowed its banks a percentage of the discharge was added, depending on the depth and velocity of the overflowed portion. For stages below that portion of the curve which is fixed by discharge measurements, the curve was extended, following the general form of the determined lower portion. Notes under each rating table indicate those portions that are based on actual gagings, and those that are estimated. From the rating table and daily gage heights, a table giving the daily discharge of the stream was prepared. From this the table of estimated monthly and yearly discharges and run-off was computed, which gives in a condensed form the observations made during the year at the station.

The column headed "maximum" gives the mean flow for the day when the mean gage height was the highest, as given in the rating table for that mean gage height. As the gage height is the mean for the day, there might have been short periods when the water was higher and the corresponding discharge

larger than that given in this column. Likewise, in the column headed "minimum" the quantity given is the mean flow for the day when the mean gage height was the lowest. The column headed "mean" gives the average for each second of the month. Upon these the computations for the two remaining columns are based.

The expression "second feet per square mile" means the average number of cubic feet of water flowing from each square mile of drainage area for each second.

Fig. 20. Current Meter Rating Station, Pedro Miguel.

"Depth in inches" means the depth of water in inches that would have covered the drainage area, uniformly distributed, if all the water could have accumulated on the surface. This quantity is used for comparing run-off with rainfall. It should be noted that "depth in inches" represents the actual quantity of water produced during the period in question, while "second feet" is merely the rate of flow, into which the element of time does not enter.

Hydrographic Stations.

The New French Company inaugurated an exhaustive study of the hydrographic conditions pertaining to the construction of an interoceanic canal, whereas the records of the Old French Company were incomplete and unsatisfactory in detail. The New French Company operated stations at Gamboa, Bohio and Alhajuela, where valuable data concerning the regimen of the Chagres River and its tributaries were collected, but unfortunately they do not contain any flood discharges so great as those which occurred during the régime of the Old Company.

Previous to 1907 discharge measurements were made from the observation of floats. In 1899 and 1900 current meter measurements were made on the Chagres and its tributaries, also on the Rio Grande and Pedro Miguel, under the direction of Mr. Arthur P. Davis, Chief Hydrographer of the Isthmian Canal Commission. (See report of March 15, 1901, addressed to Rear Admiral J. G. Walker, President of the Commission.) During 1907 both float and current meter observations were made at Bohio and Alhajuela. Current meter measurements alone have been used since January, 1908, except at times when conditions rendered it impossible to operate the instruments. Comparative tests seem to indicate that the results obtained from float measurements were higher than the gage heights warranted, but no corrections have been applied to the data as published, since they were undoubtedly the very best obtainable at the time, and, if in error, the error was on the side of safety.

Since 1907 all gaging stations have been fully equipped with modern current meter apparatus; and cross-sections have been regularly taken and the meters rated at frequent intervals. During the dry season, wherever practicable, gagings were made by wading in the streams. This method was found especially valuable in gaging the flow through the concrete channel at the Gatun Spillway during the dry season of 1912.

Gamboa has the longest record of any hydrographic station on the Isthmus. Gagings by floats were made prior to 1888, but no continuous records of river heights were obtained until that year, when an automatic register was installed. The Gamboa station is located near the point where the Canal leaves the valley of the Chagres, the valley ascending from this point to

the northeast, while the Canal axis proceeds to the southeast across the Continental Divide to the Pacific. The backwater from Gatun Lake was felt appreciably at this station about the 1st of September, 1912. Gaging work was further complicated by the filling in of the river channel along the north bank following the gravel excavation of the dry season of 1912. Regular gaging work at Gamboa was discontinued at the end of 1912, although a few measurements have been made on extreme low water and during all freshets of any moment. Owing to back-

Fig. 21. Water Stage Register, Gatun, 1914.

water effects of the lake, the station was moved, in 1913, further down stream to within about one thousand feet of the Canal prism, where an automatic water-stage register records continuous lake heights, which are tabulated into bi-hourly values.

Bohio station was established in 1891, but continuous record of discharge measurements is available only since 1893, when an automatic instrument was installed. These records were continued until the backwater from Gatun Lake, in October, 1910, prevented further gagings. The automatic water-stage register was, however, continued in operation, from which bi-hourly lake heights are tabulated.

Alhajuela, situated about eleven miles above Gamboa, was established April 15, 1899, when an automatic record was commenced, and is in operation at the present time. The measurements at this station are checked by gagings on the upper Chagres, Pequeni and La Puenta Rivers near Vigia. Its principal use is to continue observations of river heights and discharge measurements for comparative purposes, and to serve as a flood warning station for advance information governing the operation of the spillway gates at Gatun.

A station was established at Vigia, about eight miles above Alhajuela, in August, 1908, as a flood warning station. The elevation of the bottom of the river is + 125 ft. above sea level. During the flood of December 26, 1909, the water rose to a maximum height of 168.9 feet above mean sea level.

Gatun gaging station was established in May, 1907, at which time an automatic instrument was installed, and is still in operation as a water-stage register station for recording bi-hourly lake heights. Since April, 1910, the entire run-off of the Chagres basin has passed through the Spillway, where a fully equipped gaging station is in operation at the lower end of the discharge channel.

On account of tidal conditions existing at Gatun, it was impossible to secure with precision the low-water flow prior to the building of Gatun Dam. Stations were therefore established on the Trinidad and Gatun Rivers, and the total of their discharge added to that of Bohio was considered the discharge at Gatun during low-water stages. Tidal influences were felt as far inland as Bohio, and during low-water stages gagings were made at the Buena Vista Station, about one mile above the regular Bohio gaging station.

The stations on the Trinidad and Gatun Rivers were established in May, 1907, and continued in operation for four years, when, on account of backwater on the lake having reached a height permitting the entire flow to pass through the spillway, they were no longer used for gaging purposes. Water-stage registers are still maintained in the arms of the lake formed by the Trinidad and Gatun Rivers, at which continuous bi-hourly heights are recorded.

To facilitate the study of any phenomena accompanying the

filling of Gatun Lake, water stage registers recording the bi-hourly heights were installed at Frijoles, San Pablo and at the north end of Pedro Miguel locks.

On account of backwater from Miraflores Lake, the gaging station on the Pedro Miguel River was abandoned November, 1913, and a water-stage register recording the bi-hourly heights was installed on Miraflores Lake, at the south end of Pedro Miguel locks.

In connection with the study of rainfall and run-off since January, 1912, rainfall stations (in addition to those maintained prior thereto) have been in operation on the Chagres at the junction of the Rio Indio, and on the Pequeni at the junction of the Culebra; also on the Chilibrillo, on the Azules at its junction with the Caño, at Los Rieces and Quipo on the Siri, and Cucherbo on the Trinidad, thus affording a well distributed system of rain gages over these outlying valleys of the drainage basin.

The maximum measured discharge for one year at Alhajuela, Gamboa and Bohio was that of 1909, while for Gatun it was that of 1910, owing to the fact that the large volume of water contributed by the flood of November and December, 1909, was retarded below Bohio by the large swamp areas, dense forest and jungle growth. The maximum discharge at all stations occurred during the river year 1909-1910 (May 1, 1909 to April 30, 1910).

The year of minimum run-off for all stations was 1905 and the minimum dry season run-off was 1912.

Floods.

The following are the principal floods which have occurred on the Chagres River since the Canal operations were inaugurated, to December, 1914.

The records of the Panama Railroad show that no damage to the road occurred prior to the flood of 1879.

The descriptions of the floods prior to 1906, except that of 1879, are taken from General Abbott's translation of the French records, and the discharge estimates are deduced in accordance with the formulae expounded by this learned hydrologist and student, whose book, "Problems of the Panama Canal", is pre-eminently the most reliable and exhaustive of any on the subject.

Flood of 1879: The report of Acting Superintendent Dow of the Panama Railroad states that: "A heavy 'Norther' commenced at 9 p. m., November 20, 1879. The French collier 'Georges', the collier 'E. H. Peck', and the 'Albatross' were wrecked during the night. The American brig 'Adele McLoon' was wrecked during the 21st. The sea was so heavy that the American vessel 'Addie J. Bonner', fully laden with coal, with two anchors down, struck bottom in five fathoms of water and lost her rudder.

"Throughout the 22nd and 23rd, and until noon of the 24th, the wind, sea, and rain continued with unabating fury. At noon of the 24th the wind moderated a little, the sea began to subside, and the rain changed from a steady downpour to heavy showers at intervals. On the 25th, the wind died out, but heavy rains and showers continued".

Assistant Superintendent Wood states: "From mile post 4 the track has been under water for twenty-nine (29) consecutive miles, with, perhaps, the exception of a few hundred feet at the summit of Tiger Hill." The elevation of the track at Tiger Hill is 31.8 feet, and twenty-nine miles from mile post 4 would be at Las Cascadas.

Maximum height at Gamboa was 82.6 feet above mean sea level, with a discharge of 78,614 cu. ft. per second.

Boyd Ehle gives maximum height of this flood at Gamboa as 87.5 feet above mean sea level.

Flood of 1885: This flood presented peculiar features. The rise at Gamboa began November 25th from level about 6.5 feet above low water, mounted steadily for thirty-six hours to a maximum height of 78.4 feet above mean sea level, then subsided rapidly nearly to the 10-foot level, there oscillating for five days, and finally, on December 3-5, developed into another rise, smaller than the first, but quite comparable, at Gamboa, with that of 1893. The maximum height at Gamboa was 78.4 feet at 8 p. m., November 26th, with a discharge of 64,488 cu. ft. per second. The second rise reached its maximum height at 6 p. m., December 3rd, with a discharge of 44,923 cu. ft. per second. The greatest average for 48 hours occurred between 8 p. m., November 25th, and 8 p. m., November 27th, being 43,404 cu. ft. per second.

Flood of 1888: This flood, although it attained a height of about 8 inches less than that of 1890, was more formidable on account of its duration. The rise at Gamboa began on December 11th from a level about 2 ft. above low water, mounted rapidly about 22 feet, subsided slightly only to resume its upward movement, attaining its highest point, 77.3 feet, on December 13th, subsided gradually for forty-eight hours and then developed into a large freshet, and finally fell on December 17th below the 10-foot stage. The maximum height at Gamboa was 77.3 feet above mean sea level at 9 p. m., December 13th, with a maximum discharge of 58,132 cu. ft. per second. The largest average discharge in forty-eight hours occurred between noon of December 12th and noon of the 14th, being 48,278 cu. ft. per second.

Flood of 1890: This flood was of quite a different type from that of 1893. The river at Gamboa rose rapidly about twenty-five feet in seventeen hours and immediately subsided twenty-one feet in twenty-three hours. This flood was more destructive than that of 1893. In the morning of December 1st the river began to rise rapidly, carrying huge drift logs and debris of every description. At 9 p. m. it had reached the flooring and swept away part of the bridge at Gorgona, wrecked a dredge, and done other damage. Railroad communication between Matachin and Gorgona had already been interrupted, with five feet of water on the track; it soon stood 1.5 feet deep on the line between Bohio and Barbacoas and between Lion Hill and Gatun, and at 2 a. m., December 2nd, it had overflowed the line between Frijoles and Tabernilla. Traffic was restored on December 3rd. The maximum height at Gamboa was 77.8 feet above mean sea level at 8 p. m., December 1st, with a discharge of 65,371 cu. ft. per second. The largest average discharge in forty-eight hours at Gamboa occurred between 2 a. m., December 1st and December 3rd, being 34,752 cu. ft. per second.

Flood of 1893: After moderate showers on the 14th, 15th and 16th of December, a heavy rainfall began on the evening of the 17th and continued until the 24th. During these seven days, 13.9 inches of rain fell at Gamboa. The wind shifted from south to west and northwest, and blew in squalls and heavy gusts. The maximum height at Gamboa was 71.2 feet above mean sea level at 10 a. m., December 21st, with a discharge of

43,032 cu. ft. per second. The largest discharge in forty-eight hours occurred between 10 p. m., December 20th, and 10 p. m., December 22nd, being 27,971 cu. ft. per second.

Flood of 1906: The flood of 1906 is quite similar to that of 1885, being characterized by two distinct rises at nearly the same dates in both years, and being not unlike in volume; but it differs, in that the larger outflow followed instead of preceding, as in 1885. The first small rise was due to the rainfall which prevailed over the whole Isthmus on November 15th, 16th and 17th, but, what is very unusual, the larger downfall exceeded 4.00 inches at several stations on the Pacific side of the divide, where it did not contribute to swell the Chagres. The maximum height at Gamboa was 81.7 feet above mean sea level with a discharge of 76,066 cu. ft. per second, the average maximum discharge for forty-eight hours being 42,377 cu. ft. per second.

The hydrology of this great flood is fully set forth in the report of Mr. R. M. Arango, Division Engineer, to the Chief Engineer, as follows:

"I beg to submit the following report in connection with one of the greatest floods yet recorded on the Chagres River, which is without doubt second only to that of 1879, and far surpassing in magnitude the five previously recorded since the French Company began operations in the Canal route.

"Our records show that the month of November had been one of exceptional heavy rainfalls, and from the 15th to the 18th a freshet of such magnitude swept down the stream that we were induced to consider it a quasi flood and to class it as one of the smallest of the great rises of the river. After the occurrence, there was a steady downpour over almost the entire Isthmus. From November 21st to December 1st, there had fallen at Colon 7.51 inches, at Alhajuela 5.98, at Gamboa 5.71, and Bohio 3.28. By the end of the 2nd of December the distribution on the basin was 11.75 inches at Colon, 8.78 inches at Alhajuela, 8.96 inches at Gamboa, and 6.10 inches at Bohio. On the 3rd of December the precipitation increased, the rainfall for that day being 4.75 inches at Colon, 5.16 inches at Alhajuela, 3.71 inches at Gamboa, 3.59 inches at Bohio. These heavy showers of the 2nd and 3rd on ground almost saturated with water produced the great rise which began to be felt at Alhajuela at 2 p. m. on the 2nd, at

Gamboa 6 p. m., reaching Bohio at 10 o'clock on the night of the 2nd. At Alhajuela the rise was sudden. In twenty hours the maximum elevation was reached, the river attaining here a height above low water of 26.89 feet and discharging 92,100 cubic feet per second.

"At Gamboa, twenty-four hours after its effects were noticed, the river had risen 35.65 feet above low water mark, or 81.7 feet above mean sea level, the discharge at this stage being 76,066 cubic feet per second. Once the maximum was attained, the river dropped rapidly, and after thirty-six hours it had subsided 29 feet. The crest of the wave did not reach Bohio until 7 a. m. of the 4th, where its elevation was 38.36 feet above low water mark, which is sea level at that place. The discharge at this stage was 108,205 cubic feet per second. At 9 a. m., the elevation had dropped to 36.65 feet, then descended gradually until 4 p. m. of the 6th, when it had dropped below the freshet stage. To obtain comparisons between this and previous floods, we can only refer to our estimates for Gamboa and Bohio, as these are the only stations at which past floods of the Chagres have been recorded. Considering the maximum discharge per second of time, there is no doubt that the present flood surpassed all previous ones in magnitude." (Mr. Arango here refers to floods actually gaged, not including the flood of 1879, in which only extreme heights were recorded.) "If, on the other hand, we accept 48 hours as the period of danger at Gamboa, with the object of comparing these great rises with a view of regulation before admitting them to the waterway, we must conclude that in magnitude it fell below the floods of 1885 and 1888, due to the shorter duration of its high stage at the station.

"At Bohio, the conditions were different, the rise and fall being more gradual, as the lower tributaries contributed well towards the flood, and the reserve volume stored in the flooded areas of the lower sub-basin maintained its duration during a long period, making the resulting figures of our estimates far above those obtained by General Abbott on this subject." (Mr. Arango here refers to floods actually gaged, not including that of 1879, of which only extreme heights were recorded.) "The only flood approaching it in magnitude at Bohio was the flood

of 1888, which during a period of 33 hours discharged at the rate of 73,320 cubic feet per second, while for the same period the present flood discharged 84,956 cubic feet per second.''

Flood of 1909: Two great floods occurred during this year, the hydrology of which cannot be better described than to quote from the report of Mr. C. M. Saville, Assistant Engineer in charge of the Third Division:

''Flood conditions existed during about half the month of November, the maximum elevation at Gamboa being 72.6 feet on November 19, 1909, nine feet below the flood of December, 1906. This flood carried the highest water at Gatun, where an elevation of 21.5 feet was reached. This extreme height was caused by previous rainy conditions which had caused the water to back up at Gatun, so there was already high water at that station before the freshet rains of this period. At this time, it is estimated that an area of 32.47 square miles was flooded with a volume of 9,652,277,000 cu. ft. At Vigia, the observer was obliged to abandon his house, and the water-stage register was flooded. Accurate records were kept, however, by staff readings during the time the automatic register was out of commission. At Gatun, the washing away of construction railway trestles destroyed the automatic register, but river elevations were taken from staff gage. About two and one-half times the usual amount of water for the period passed this station during the flood, which, if all had been retained, it is estimated would have raised the elevation of Gatun Lake to about elevation 48.8 above sea level, or about one-third full. (Gatun Lake maximum elevation + 87.) If the total discharge from January 1, 1909, had been impounded, Gatun Lake would have been filled by the middle of October and almost half as much wasted. The maximum height at Lagartera on the Trinidad, which occurred simultaneously with that at Gatun, was elevation 24.05, about 2.50 feet higher than the crest at the latter point, which gave a drop of less than one-quarter foot per mile. This condition resulted in the retention of the run-off above Lagartera, so the maximum discharge at this station, 4,200 cu. ft. per second, occurred some time subsequent to the maximum height.

''Three important freshets occurred during December. The first, which was due almost entirely to rainfall in the Chagres

basin above Vigia, was reported from that station on the morning of the 6th and the river reached almost the same elevations at Vigia and Alhajuela as were reached by the flood of the previous month, but at the other stations in the river, the elevations were from four to seven feet lower than those of the previous month.

"The greatest flood of the year began on the 26th. The river rose rapidly, and within eight hours after the beginning of the rise at Vigia, the observer's house and water stage register had been washed away. The register at Alhajuela similarly suffered, and telephone communication was interrupted. The crest passed Alhajuela at elevation 121.0, two feet higher than the crest of the flood of December, 1906. At Gatun, the elevation of this crest, which passed one and one-half days later, was 19.5, as against 21.5 reached by the November flood. The greatest previous flood of authentic record was that of December, 1906, and the following comparisons are given of gage heights and discharges:

	December, 1906*		December, 1909†	
Station	Elev. Crest	Max. Discharge	Elev. Crest	Max. Discharge
Alhajuela	119.3	92,100	121.0	170,000
Gamboa	81.6	76,066	78.2	168,000‡
Bohio	38.6	108,026	38.7	90,000§
Gatun	....	....	19.6	63,400§

Note:—Elevations are in ft. above mean sea level, and discharges in cu. ft. per sec.

"Before the high water of this flood had subsided, another freshet occurred on the 30th and 31st, the crest of which reached 112.0′ at Alhajuela, 32.1′ at Bohio, and 17.7′ at Gatun. Much territory was flooded during all these rises, and during the highest water travel was interfered with on the Panama Railroad, due to submergence of tracks".

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* From Abbott's Problems, Panama Canal, page 149.

† Gagings and observations by Third Division, Office of Chief Engineer.

‡ Estimated from Alhajuela discharge and observed conditions at Gamboa.

§ The comparatively small discharge at these stations is due to regulation of runoff by poundage in Gatun Lake area. This is shown by inspection of curve on plate 35.

Flood of 1910: The flood of December 3, 1910, was the greatest that had occurred since the beginning of the formation of Gatun Lake.

The entire discharge at Gatun passed through the spillway of Gatun Dam, but on account of a log jam, no accurate measurements could be obtained. The maximum height at Alhajuela was 108.7 ft., with a discharge of 60,300 cu. ft. per second.

Flood of 1911: This flood occurred on February 12th and 13th, during the dry season. The maximum height at Alhajuela was 105.5 ft., with a discharge of 43,600 cu. ft. per second; the average rate of discharge for the twenty-four-hour period being 17,280 cu. ft. per second.

Flood of 1912: After having had two freshets on the Chagres on the 26th and 27th of November, a third rise started at 7:00 p.m. on the 27th, the elevation at Alhajuela being 96.3 ft. The crest passed at 1:30 p.m., the 28th, maximum elevation 108.4 ft., with discharge of 58,000 cu. ft. per second.

This freshet compares closely with that of December, 1910, being the largest since that date.

Comparison of Freshets of Large Moment.

	December, 1909	December, 1910		November, 1912	
	Elev. ft.	Elev. ft.	Discharge cu. ft. sec.	Elev. ft.	Discharge cu. ft. sec.
Alhajuela.......	121.0	108.7	60,300	108.4	58,000

Run-off.

The relation of rainfall to run-off depends upon numerous factors discussed below, but it may be said in general that the least run-off occurs in loose and well drained sandy soil having a large storage capacity, and the greatest in hilly and mountainous regions. It is evident that hilly and mountainous land will have a greater rate of run-off during storms than flat land, and, in fact, this difference is very marked in many instances. On the Isthmus of Panama three characteristic divisions may be noted.

First, in the rugged or precipitous mountain or hill land, from which the run-off is torrential. Here the streams, which form narrow gullies between ranges of hills, have steep channel slopes, and the water which falls as rain, finds its way to gullies and water courses, and within a few hours after falling is in the main channel on its way to the outlet.

TABLE 26.

DISCHARGE TABLE

ALHAJUELA

Cubic Feet per Second — Watershed Area - 427 Sq.Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	2140*	1095G	918G	883G	3249G	4061G	4097G	4309G	5191G	4909G	3002G	4485G	3195
1891	1554G	777G	494G	424G	2649G	1801G	2861G	2119G	2296G	3390G	5686G	3665G	2328
1892	1165G	918G	812G	1695G	4203G	2649G	5651G	4626G	3320G	4521G	5509G	4627G	3308
1893	1731G	1660G	1024G	2402G	2331G	2437G	2719G	3602G	2967G	2860G	3461G	6110G	2775
1894	2825G	1342G	777G	600G	1059G	1695G	3390G	2967G	3390G	3567G	4980G	8086G	2590
1895	2684G	1236G	742M	918G	1483M	2048M	1801M	2543M	1907M	3638M	2543M	3920M	2122
1896	2437M	1059M	600M	1271M	2543M	2225M	2225G	2154M	2154M	2048M	2472M	3885G	2089
1897	1342G	918G	424G	563G	2507G	1801G	2861G	3108G	2931G	2931G	3390G	3532G	2192
1898	3284G	1236G	849G	1519G	1872G	2190G	3214G	3143G	1907G	2649G	3955G	1731G	2296
1899	2684G	777G	777G	883F	1589F	2154F	2225F	3284F	2402F	2649F	2931F	2260F	2051
1900	1589F	812F	530F	565F	1342F	1554F	2190F	2825F	2154F	3214F	2967F	2296F	1837
1901	989F	671F	459F	459F	1554F	1731F	1976F	2437F	2931F	2755F	4768F	3037F	1981
1902	4236	1271	812	1695	2119*	2190	2119	2331	2366	3214	3143	1836	2278
1903	1130	846	494	565	1377	1942	3108	3178	2790	2755	4009	5474	2306
1904	3002	1589	954	2190	1820	2659	2677	1579	2834	2031	4143	2350	2319
1905	1416	777	576	442	1932	1594	1246	2207	1722	2668	2267	1265	1512
1906	682	613	434	711	1098	1363	3019	3242	2783	2080	3433	7283	2228
1907	3995	1376	1013	652	2132	2989	4225	2955	3904	4583	3866	2896	2882
1908	1005	582	585	592	2595	2213	2639	3007	3710	3611	6400	4123	2588
1909	4040	3315	1155	1110	2420	4870	3300	4090	3560	3665	11300	17300	5010
1910	5050	2870	1625	3140	6220	3310	4420	4400	4339	4398	4490	5964	4102
1911	1640	2310	881	1689	2790	2881	2609	2359	1830	2407	3553	1391	2195
1912	734	516	382	371	1682	1857	2592	2580	2853	3040	5541	3058	2100
1913	1795	1177	695	501	2051	1995	2005	2530	2802	2653	6168	2328	2225
1914	1306	824	530	468	2049	2084	1399	2066	4334	5135	3804	3213	2269
Mean 25Yrs.	2171	1223	745	1052	2227	2332	2823	2946	2935	3256	4511	4253	2523

* Monthly means. G From Gamboa:Alhajuela ratio.
M Mean of measured discharges. F From formulas.

TABLE 27.

DISCHARGE TABLE

ALHAJUELA

Cubic Feet per Sec. per Sq. Mi. — Watershed Area - 427 Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Mean
1890	5.02	2.56	2.15	2.07	7.61	9.51	9.59	10.09	12.16	11.50	7.03	10.49	7.48
1891	3.64	1.82	1.16	0.99	6.20	4.22	6.70	4.96	5.38	7.94	13.32	9.10	5.45
1892	2.73	2.15	1.90	3.97	9.84	6.20	13.23	10.84	7.78	10.59	12.91	10.83	7.75
1893	4.05	3.89	2.40	5.62	5.46	5.70	6.36	8.44	6.95	6.70	8.11	14.31	6.50
1894	6.62	3.14	1.82	1.41	2.48	3.97	7.94	6.95	7.94	8.35	11.67	18.94	6.77
1895	6.29	2.90	1.74	2.15	3.47	4.79	4.22	5.96	4.47	8.52	5.96	9.18	4.97
1896	5.70	2.48	1.41	2.98	5.96	5.21	5.21	5.05	5.05	4.79	5.79	9.10	4.90
1897	3.14	2.15	0.99	1.32	5.87	4.22	6.70	7.28	6.86	6.86	7.94	8.27	5.13
1898	7.69	2.90	1.99	3.56	4.39	5.13	7.53	7.36	4.47	6.20	9.26	4.05	5.38
1899	6.29	1.82	1.82	2.07	3.72	5.05	5.21	7.69	5.62	6.20	6.86	5.29	4.80
1900	3.72	1.90	1.24	1.32	3.14	3.64	5.13	6.61	5.05	7.52	6.95	5.38	4.30
1901	2.32	1.57	1.08	1.07	3.64	4.05	4.63	5.71	6.86	6.45	11.16	7.11	4.64
1902	9.93	2.98	1.90	3.97	4.96	5.13	4.96	5.46	5.54	7.53	7.36	4.30	5.34
1903	2.65	1.99	1.16	1.32	3.23	4.52	7.28	7.44	6.53	6.45	9.39	12.82	5.40
1904	7.03	3.72	2.23	5.13	4.26	6.22	6.27	3.70	6.64	4.76	9.70	5.50	5.43
1905	3.32	1.82	1.35	1.04	4.52	3.73	2.92	5.17	4.03	6.29	5.31	2.96	3.54
1906	1.60	1.44	1.02	1.67	2.57	3.19	7.07	7.59	6.52	4.87	8.04	17.06	5.22
1907	9.35	3.22	2.37	1.53	5.00	7.00	9.90	6.92	9.14	10.74	9.05	6.78	6.75
1908	2.35	1.36	1.37	1.39	6.08	5.18	6.18	7.04	8.69	8.46	14.99	9.66	6.06
1909	9.46	7.76	2.71	2.60	5.67	11.41	7.73	9.58	8.34	8.58	26.48	40.52	11.74
1910	11.83	6.72	3.81	7.36	12.22	7.75	10.36	10.31	10.16	10.30	10.51	13.97	9.61
1911	3.84	5.41	2.06	3.96	6.53	6.75	6.11	5.52	4.29	5.64	8.32	3.26	5.14
1912	1.72	1.21	.89	.87	3.94	4.35	6.07	6.04	6.68	7.12	12.89	7.16	4.92
1913	4.20	2.76	1.63	1.17	4.80	4.67	4.70	5.92	6.56	6.21	14.44	5.45	5.21
1914	3.06	1.93	1.24	1.10	4.80	4.88	3.28	4.84	10.15	12.03	8.91	7.52	5.31
Mean *25Yrs.	5.10	2.86	1.74	2.47	5.21	5.46	6.61	6.90	6.87	7.62	10.10	9.96	5.91

TABLE 28.

DISCHARGE TABLE

ALHAJUELA

Inches on Watershed — Watershed Area - 427 Sq. Mi.

[illegible]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1890	[illegible]	2.666	2.479	2.309	8.773	10.610	11.056	11.629	13.566	13.260	7.843	12.098	102.077
1891	4.197	1.895	1.337	1.105	7.148	4.708	7.724	5.718	6.002	9.154	14.864	10.491	74.343
[illegible]	3.147	2.319	2.190	4.429	11.344	6.917	15.253	12.498	8.680	12.209	14.401	12.486	105.873
[illegible]	4.669	4.051	2.767	6.270	6.295	6.359	7.332	9.730	7.754	7.724	9.048	16.501	88.500
[illegible]	7.632	3.270	2.098	1,573	2.859	4.429	9.154	8.013	8.859	9.627	13.017	21.834	92.365
1895	7.252	3.020	2.006	2.399	4.001	5.344	4.865	6.871	4.987	9.823	6.650	10.584	67.802
[illegible]	6.583	2.675	1.626	3.325	6.871	5.813	6.007	5.822	5.634	5.522	6.460	10.491	66.829
1897	3.620	2.239	1.141	1.473	6.767	4.708	7.724	8.398	7.654	7.909	8.859	9.534	70.021
1898	8.866	3.020	2.294	3.972	5.061	5.724	8.681	8.485	4.987	7.148	10.331	4.669	73.238
[illegible]	7.252	1.895	2.098	2.309	·4.289	5.634	6.007	8.866	6.270	7.148	7.654	6.099	65.521
1900	4.289	1.979	1.430	1.473	3.620	4.061	5.914	7.621	5.634	8.681	7.754	6.203	58.659
1901	2.675	1.635	1.245	1.194	4.197	4.519	5.338	[illegible]	7.654	7.436	12.452	8.197	63.125
1902	11.448	3.103	2.190	4.429	5.718	5.724	5.718	6.295	6.181	8.681	8.212	4.957	72.656
1903	3.055	2.072	1.337	1.473	3.724	5.043	8.393	8.578	7.286	7.436	10.476	14.782	73.655
1904	8.105	4.012	2.571	5.724	4.911	6.940	7.229	4.266	7.408	5.488	10.822	6.341	76.817
1905	3.828	1.895	1.556	1.160	5.211	4.162	3.366	5.960	4.496	7.252	5.924	3.413	48.223
[illegible]	1.845	1.500	1.176	1.863	2.963	3.559	8.151	8.750	7.274	5.615	8.970	19.666	71.332
1907	10.780	3.353	2.722	1.707	5.764	7.810	11.414	7.978	10.197	12.384	10.097	7.817	92.033
[illegible]	2.709	1.467	1.579	1.551	7.010	5.779	7.125	8.116	9.695	9.753	16.728	11.137	82.649
[illegible]	10.906	8.081	3.124	2.901	6.537	12.731	8.912	11.045	9.305	9.892	29.546	46.714	159.694
1910	13.636	6.998	4.393	8.212	14.092	8.647	11.942	11.882	11.336	11.870	11.722	16.107	130.837
1911	4.427	5.634	2.375	4.418	7.528	7.531	7.044	6.364	4.786	6.502	9.283	3.758	69.650
1912	1.983	1.305	1.031	.970	4.542	4.853	6.998	6.963	7.453	8.209	14.482	8.255	67.004
1913	4.842	2.874	1.877	1.310	5.534	5.210	5.419	6.825	7.319	7.159	16.111	6.283	70.673
1914	3.528	2.010	1.430	1.227	5.534	5.445	3.781	5.580	11.325	13.869	9.941	8.670	72.340
[illegible] 25Yrs.	5.882	2.999	2.005	2.751	6.012	6.090	7.622	7.953	7.670	8.790	11.266	11.483	80.521

TABLE 29.

DISCHARGE TABLE

GAMBOA

Cubic Feet per Second — Watershed Area - 559 Sq.Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	2756	1342m	1095m	1059	4273	5353	5403m	5686m	6816m	6498m	3956m	5898m	4176
1891	2048m	954m	600m	530m	3461m	2366m	3779m	2790m	3037m	4450m	7487m	5121m	3052
1892	1519m	1095m	989m	2048m	5509	3496	7416	6075	4379	5923	7240	6075	4314
1893	2296	2013	1236	2931	3037	3214	3567	4732	3885	3744	4556	8052	3605
1894	3708	625	954	742	1377	2225	4450	3885	4450	4697m	6534m	10630m	3690
1895	3532	1483	1095m	1130	3461	3178	3073	4061	3390	4944	3532	3779	3055
1896	2225	1130	636m	1342m	4450m	4132	2931	2331m	2719m	2684m	3249	5121m	2746
1897	1760m	1130	494m	671	3284m	2366m	3779m	4097m	3850m	3850	4450	4626	2863
1898	4309	1483	1024	1836	2472	2861	4238	4132	2543	3461	5192	2296	2987
1899	3496	954	954	1059	1907	2472	2825	4238	3178	3390	3744	2649	2572
1900	1695	812	530	565	1342	1942	3355	3567	3073	4520	4061	2684	2346
1901	1024	671	459	459	1766	2048	2190	2861	3638	3702	6746	3143	2392
1902	5227	1589	1024	1942	2896	2896	3002	2790	2931	4415	4732	2190	2970
1903	1625	918	706	706	1519	2154	3320	4344	4697	3956	5721	7028	3058
1904	4132	2402	1695	2861	2275	3073	3271	2142	3822	2974	4561	2711	2993
1905	1687	1052	844	703	2183	2091	1684	2613	2231	3480	2585	1835	1914
1906	1020	783	610	849	1916	1949	3835	4137	3781	2782	5252	7756	2869
1907	2935	1297	1011	687	1446	2879	5560	3890	5140	6030	5090	3810	3515
1908	1230	710	710	720	3410	2910	3470	3960	4880	4750	8420	5820	3416
1909	4930	4040	1410	1350	3180	6410	4340	5380	4680	4820	14870	22760	6514
1910	6160	3500	1980	3850	6870	4360	5820	5790	5710	5790	5652	8078	5295
1911	1766	2362	976	1756	3178	3020	3516	2781	2348	3319	4856	1528	2617
1912	801	542	366	372	1777	2161	3151	3190	3694	4249	6934	3309	2636
Mean 23Yrs.	2691	1429	930	1311	2913	3023	3824	3890	3860	4279	5627	5517	3274

m - Denotes mean of all gagings during month.

TABLE 30.

DISCHARGE TABLE

GAMBOA

Cubic Feet per Second per Sq. Mi. — Watershed Area - 559 Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	4.92	2.40	1.96	1.90	7.64	9.54	9.67	10.18	12.20	11.61	7.07	10.54	7.47
1891	3.66	1.71	1.07	.95	6.19	4.23	6.76	4.99	5.43	7.96	13.40	9.16	5.46
1892	2.72	1.96	1.77	3.66	9.86	6.25	13.27	10.88	7.83	10.60	12.95	10.88	7.72
1893	4.11	3.60	2.21	5.24	5.43	5.75	6.38	8.47	6.95	6.70	8.15	14.40	6.45
1894	6.63	1.12	1.71	1.33	2.46	3.98	7.96	6.95	7.96	8.40	11.69	19.02	6.60
1895	6.32	2.65	1.96	2.02	6.20	5.68	5.50	7.27	6.06	8.84	6.32	6.76	5.47
1896	3.98	2.02	1.14	2.40	7.96	7.40	5.25	4.17	4.86	4.80	5.81	9.16	4.91
1897	3.15	2.02	.88	1.20	5.87	4.23	6.76	7.32	6.88	6.86	7.96	8.27	5.12
1898	7.70	2.65	1.83	3.28	4.42	5.12	7.58	7.39	4.55	6.20	9.29	4.10	5.34
1899	6.25	1.71	1.71	1.89	3.41	4.42	5.05	7.58	5.68	6.06	6.70	4.74	4.60
1900	3.03	1.46	.91	1.01	2.40	3.47	6.00	6.38	5.50	8.08	7.26	4.80	4.20
1901	1.83	1.20	.82	.82	3.16	3.66	3.92	5.12	6.50	6.62	12.07	5.62	4.28
1902	9.35	2.84	1.83	3.47	5.18	5.18	5.37	4.99	5.24	7.90	8.47	3.92	5.31
1903	2.91	1.65	1.27	1.27	2.72	3.85	5.94	7.77	8.40	7.08	10.23	12.57	5.47
1904	7.39	4.30	3.03	5.12	4.07	5.50	5.85	3.83	6.84	5.32	8.16	4.85	5.36
1905	3.02	1.84	1.51	1.26	3.91	3.74	3.01	4.67	3.99	6.23	4.62	3.28	3.42
1906	1.82	1.40	1.09	1.52	3.43	3.49	6.86	7.40	6.76	4.98	9.39	13.88	5.17
1907	5.25	2.32	1.81	1.23	2.59	5.15	9.95	6.96	9.20	10.78	9.10	6.82	5.93
1908	2.20	1.27	1.27	1.29	6.10	5.20	6.20	7.08	8.73	8.50	15.05	10.41	6.11
1909	8.82	7.22	2.52	2.42	5.69	11.46	7.76	9.62	8.37	8.62	26.60	40.71	11.65
1910	11.01	6.26	3.54	6.85	12.29	7.80	10.41	10.36	10.20	10.36	10.11	14.42	9.47
1911	3.16	4.22	1.75	3.14	5.68	5.40	6.29	4.98	4.20	5.94	8.68	2.73	4.68
1912	1.45	.97	.66	.67	3.18	3.87	5.60	5.71	6.43	7.60	12.40	5.92	4.54
Mean 23Yrs.	4.81	2.56	1.66	2.35	5.21	5.41	6.84	6.96	6.90	7.66	10.06	9.87	5.86

TABLE 31.

DISCHARGE TABLE

GAMBOA

Inches on Watershed — Watershed Area - 559 Sq. Mi.

[illegible]	Jan.	Feb.	Mar.	Apr.	[illegible]	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1890	5.672	2.499	2.260	2.120	8.808	10.644	11.148	11.736	13.610	13.382	7.888	12.164	101.921
1891	4.220	1.761	1.234	1.060	7.136	4.719	7.794	5.753	6.058	9.177	14.950	10.560	74.442
1892	3.136	2.114	2.041	4.083	11.367	6.973	15.297	12.546	8.736	12.220	14.445	12.546	105.504
1893	4.738	3.749	2.548	5.846	6.260	6.415	7.355	9.766	7.754	7.724	9.093	16.600	87.847
1894	7.644	1.166	1.971	1.484	2.836	4.440	9.177	8.013	8.881	9.684	13.039	21.924	90.259
1895	7.286	2.759	2.260	2.254	7.148	6.337	6.341	8.382	6.761	10.192	7.051	7.794	74,568
1896	4.589	2.179	1.314	2.678	9.177	8.256	6.053	4.808	5.422	5.534	6.482	10.560	67.052
1897	3.632	2.103	1.015	1.339	6.767	4.719	7.794	8.439	7.676	7.932	8.881	9.534	69.831
1898	8.877	2.759	2.110	3.659	5.096	5.712	8.739	8.520	5.076	7.148	10.366	4.727	72.768
1899	7.206	1.781	1.971	2.109	3.931	4.931	5.822	8.739	6.337	6.987	7,475	5.465	62.754
1900	3.493	1.620	1.095	1.127	2.767	3.871	6.917	7.355	6.136	9.315	8.100	5.534	57.230
1901	2.110	1.250	.945	.915	3.643	4.083	4.519	5.903	7.252	7.632	13.467	6.479	58.198
1902	10.780	2.957	2.110	3.871	5.972	5.779	6.191	5.753	5.846	9.108	9.450	4.519	72.336
1903	3.355	1.718	1.464	1.417	3.136	4.295	6.848	8.958	9.372	8.162	11.413	14.494	74.632
1904	8.520	4.638	3.493	5.712	4.692	6.136	6.744	4.416	7.631	6.133	9.104	5.592	72.611
1905	3.482	1.916	1.741	1.406	4.508	4.173	3.470	5.384	4.452	7.183	5.155	3.781	46.651
1906	2.098	1.458	1.257	1.696	3.954	3.894	7,909	8.551	7.542	5.741	10.476	16.006	70.552
1907	6.053	2.416	2.087	1.372	2.986	5.746	11.470	8.024	10.264	12.428	10.153	7.863	80.862
1908	2.536	1.370	1.464	1.439	7.033	5.802	7.148	8.162	9.740	9.800	16.795	12.002	83.291
1909	10.168	7.518	2.905	2.700	6.560	12.786	8.946	11.091	9.338	9.938	29.680	46.932	158.562
1910	12.692	6.519	4.081	7.643	14.169	8.702	12.002	11.942	11.380	11.942	11.281	16.624	128.977
1911	3.643	4.394	2.018	3.503	6.548	6.025	7.252	5.741	4.686	6.848	9.684	3.147	63.489
1912	1.672	1.045	.755	.743	[illegible]	4.318	6.456	6.583	7.174	8.762	13.855	6.825	61.834
[illegible] 23Yrs.	5.548	2.679	1.919	2.616	6.007	6.033	7.887	8.024	7.701	8.825	11.229	11.376	79.844

TABLE 32.

DISCHARGE TABLE

BOHIO

Cubic Feet per Second

Watershed Area - 779 Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	4132*	1554G	1271G	1236G	6569G	8193G	8300G	8759G	10489G	9995G	6025G	9076G	6304
1891	2684M	1377M	600M	600M	5333G	3214M	4803M	4521M	4661G	6851G	11514G	7876G	4503
1892	2331G	1271G	1165G	2366G	8476G	5439G	11407G	9359G	6746G	9112G	11125G	9359G	6513
1893	3532G	2331G	1448G	3426G	4662G	4944M	7628M	10772M	7664M	8582M	11443M	18541M	7081
1894	7063M	1801M	1045M	777M	3355M	4273M	6216M	6496M	7452M	9359M	12714M	12573M	6098
1895	4556M	1377M	1059M	1059M	4167M	4309M	4591M	6922M	5792M	6922M	6075M	6957M	4483
1896	4732M	1554M	883M	1695M	4944M	4203M	3143M	3496M	5933M	6357M	7593M	6039M	4214
1897	2048M	1589M	706M	883M	7982M	4203M	5121M	7275M	6887M	7487M	6957M	6816M	4830
1898	5651F	1695F	1095F	2013F	2684F	3355F	6569F	5298F	3214F	5050F	7840F	2861F	3944
1899	3850F	1731F	989F	1095F	2048F	3143F	5956F	5721F	4238F	4944F	5296F	3602F	3384
1900	2119F	1059F	742F	706F	1625F	2861F	5615F	5262F	4768F	6993F	6605F	3744F	3508
1901	1483F	989F	706F	365F	2296F	2790F	3178F	4309F	5792F	6322F	13244F	4591F	3855
1902	11231F	2084F	1271F	2154F	4273F	3178F	3037F	3390F	5920F	5933F	6675F	3002F	4179
1903	1625F	1024F	636F	565F	1519F	2543F	4026F	5474F	5686F	5580F	8335F	10489F	3958
1904	4944F	2331F	1413F	3638F	3037	4752	4520	3178	6674	4909	7628	4132	4261
1905	1942	989	706	600	2825	2649	1907	3884	3955	6957	4732	2860	2834
1906	1338	864	611	1002	2152	2672	5920	6356	4557	4078	7826	10654	4078
1907	3339	1396	1002	674	1854	3658	4662	3952	5664	7842	5445	3358	3570
1908	1281	681	586	666	3894	3131	3626	5491	5599	5558	9515	5046	3821
1909	4390	3580	1325	1185	3225	7010	5630	6600	5550	8230	21380	19800	7325
1910	6160	3080	1875	3760	7470	5950	9350	7910	8010	7840			
Mean 20Yrs.	3714	1564	963	1335	3846	4025	5193	5826	5807	6853	8901	5769	4637
Mean 21Yrs.	3830	1636	1006	1451	4019	4117	5391	5925	5912	6900	8901*	7569*	4721

* 1890 - 1909 inclusive

*Monthly Mean. G Gamboa:Bohio ratio.
M Mean of Measured Discharges. F From Formulas.

TABLE 33.

DISCHARGE TABLE

BOHIO

Cubic Feet per Second per Sq. Mi.

Watershed Area - 779 Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	5.31	2.00	1.63	1.59	8.43	10.51	10.65	11.25	13.47	12.82	7.80	11.64	8.09
1891	3.45	1.77	.77	.77	6.84	4.13	6.16	5.80	5.98	8.79	14.78	10.11	5.78
1892	2.99	1.63	1.50	3.04	10.88	6.98	14.65	12.01	8.66	11.69	14.28	12.01	8.36
1893	4.54	2.99	1.86	4.40	5.99	6.35	9.79	13.83	9.84	11.02	14.69	23.81	9.09
1894	9.07	2.31	1.34	1.00	4.31	5.48	7.98	8.34	9.56	12.01	16.32	16.14	7.82
1895	5.85	1.77	1.36	1.36	5.35	5.53	5.90	8.88	7.44	8.88	7.80	8.93	5.75
1896	6.08	2.00	1.13	2.18	6.35	5.40	4.04	4.49	7.62	8.16	9.75	7.75	5.41
1897	2.63	2.04	.91	1.13	10.24	5.40	6.58	9.34	8.84	9.61	8.93	8.75	6.20
1898	7.26	2.18	1.41	2.59	3.45	4.31	8.44	6.80	4.13	6.48	10.07	3.67	5.07
1899	4.94	2.22	1.27	1.41	2.63	4.04	5.08	7.34	5.44	6.35	6.80	4.62	4.34
1900	2.72	1.36	.95	.91	2.09	3.67	7.20	6.75	6.12	8.98	8.48	4.80	4.50
1901	1.90	1.27	.91	.47	2.95	3.58	4.08	5.53	7.43	8.12	17.00	5.89	4.93
1902	14.42	2.68	1.63	2.77	5.49	4.08	3.90	4.35	5.03	7.61	8.57	3.85	5.36
1903	2.09	1.31	.82	.73	1.95	3.26	5.17	7.03	7.30	7.16	10.69	13.47	5.08
1904	6.34	2.99	1.81	4.67	3.90	6.08	5.80	4.08	8.57	6.30	9.79	5.30	5.47
1905	2.49	1.27	.91	.77	3.63	3.40	2.45	4.99	5.08	8.92	6.08	3.67	3.64
1906	1.72	1.11	.78	1.29	2.76	3.43	7.60	8.16	7.00	5.24	10.04	13.68	5.23
1907	4.29	1.79	1.29	.86	2.38	4.70	5.99	5.08	7.27	10.07	6.99	4.31	4.58
1908	1.64	.87	.75	.86	5.00	4.02	4.65	7.05	7.19	7.13	12.21	6.48	4.82
1909	5.64	4.60	1.70	1.52	4.14	9.00	7.23	8.47	7.12	10.56	27.44	25.42	9.40
1910	7.91	3.95	2.41	4.83	9.59	7.64	12.00	10.15	10.28	10.07			
Mean 21Yrs.	4.92	2.10	1.29	1.86	5.16	5.28	6.92	7.60	7.59	8.86	11.43*	9.72*	6.06

* 1890 - 1909, inclusive.

TABLE 34.

DISCHARGE TABLE

BOHIO

Inches on Watershed

Watershed Area - 779 Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Total
1890	6.122	2.063	1.879	1.774	9.719	11.722	12.280	12.946	15.027	14.762	8.702	13.418	110.454
1891	3.977	1.843	.888	.859	7.886	4.608	7.102	6.687	6.672	10.134	16.488	11.652	78.796
1892	3.447	1.758	1.729	3.392	12.540	7.788	16.890	13.842	9.662	13.478	15.928	13.842	114.302
1893	5.234	3.114	2.144	4.909	6.906	7.085	11.287	15.946	10.978	12.704	16.389	27.451	124.147
1894	10.457	2.405	1.545	1.116	4.967	6.114	9.200	9.615	10.666	13.842	18.212	18.608	106.749
1895	6.744	1.843	1.568	1.517	6.168	6.170	6.802	10.238	8.301	10.238	8.702	10.295	78.586
1896	7.010	2.157	1.303	2.432	7.321	6.025	4.658	5.176	8.502	9.408	10.878	8.935	73.805
1897	3.032	2.124	1.049	1.261	11.804	6.025	7.586	10.768	9.863	11.079	9.963	10.088	84.642
1898	8.370	2.270	1.626	2.890	3.977	4.809	9.730	7.840	4.606	7.471	11.237	4.231	69.059
1899	5.695	2.312	1.464	1.573	3.032	4.507	5.857	8.462	6.069	7.321	7.587	5.326	59.205
1900	3.136	1.416	1.095	1.015	2.410	4.095	8.301	7.782	6.828	10.353	9.461	5.534	61.426
1901	2.190	1.322	1.049	.524	3.401	3.994	4.704	6.375	8.290	9.361	18.970	6.791	66.971
1902	16.624	2.791	1.879	3.090	6.329	4.552	4.496	5.015	5.612	8.773	9.562	4.439	73.162
1903	2.410	1.364	.945	.814	2.248	3.637	5.960	8.105	8.145	8.255	11.929	15.527	69.339
1904	7.309	3.225	2.087	5.210	4.496	6.783	6.687	4.704	9.562	7.263	10.923	6.110	74.359
1905	2.871	1.322	1.049	.859	4.185	3.793	2.825	5.753	5.668	10.284	6.783	4.231	49.623
1906	1.983	1.156	.899	1.439	3.182	3.827	8.762	9.408	7.810	6.041	11.204	15.768	71.479
1907	4.946	1.864	1.487	.960	2.744	5.244	6.906	5.857	8.111	11.607	7.799	4.969	62.494
1908	1.891	.938	.865	.960	5.764	4.485	5.361	8.128	8.022	8.220	13.621	7.471	65.726
1909	6.502	4.790	1.960	1.696	4.773	10.041	8.335	9.765	7.944	12.176	30.614	29.304	127.900
1910	9.119	4.554	2.689	5.566	10.700	8.808	13.830	11.702	11.468	11.607			
Mean 21Yrs	5.670	2.222	1.466	2.088	5.931	5.910	7.979	8.767	8.467	10.209	12.748*	11.200*	82.677

* 1890 - 1909, inclusive.

TABLE 35.

DISCHARGE TABLE

GATUN

Cubic Feet per Second.

Watershed Area - 1320 Square Miles.

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	6694	2518	2059	2002	10624	13273	13446	14190	16992	16102	9842	14703	10204
1891	4348	2231	972	972	8640	5207	7781	7324	7551	11099	18651	12759	7295
1892	3776	2059	1887	3833	13731	8811	18479	15162	10928	14741	18022	15162	10549
1893	5722	3776	2346	5550	7552	8009	12357	17450	12416	13903	18538	30037	11471
1894	11442	2916	1693	1259	5435	6922	10070	10527	12072	15162	20597	20368	9872
1895	7381	2231	1716	1716	6750	6981	7437	11214	9383	11214	9842	11270	7261
1896	7666	2516	1430	2745	8009	6809	5092	5664	9612	10298	12301	9783	6827
1897	3318	2574	1144	1430	12931	6809	8296	11786	11157	12129	11271	11042	7824
1898	9155	2746	1774	3261	4348	5435	10642	8583	5207	8181	12701	4635	6389
1899	6237	2804	1602	1774	3318	5092	6409	9268	6866	8009	8580	5835	5483
1900	3433	1716	1202	1144	2632	4635	9096	8524	7724	11329	10700	6065	5683
1901	2402	1602	1144	915	3720	4520	5148	6981	9383	10242	21455	7437	6246
1902	18194	3376	2059	3490	4318	5148	4920	5492	6350	9612	10814	4863	6553
1903	2632	1659	1030	915	2461	4120	6522	8868	9211	9034	13503	16992	6412
1904	8009	3776	2289	5894	4910	7652	7308	5139	10792	7938	12334	6681	6894
1905	3140	1599	1142	970	4568	4283	3083	6283	6395	11250	7652	4624	4582
1906	2164	1397	988	1620	3479	4321	8472	10277	8824	6594	12654	17237	6501
1907	5399	2257	1620	1090	2997	5915	7135	5941	8999	13479	9299	5602	5811
1908	1976	1046	851	892	5046	5025	5744	8886	8708	8859	14408	8017	5788
1909	6605	5260	2150	2215	4215	9880	9928	10980	9910	12590	28470	25800	10658
1910	11740	5080	3160	6090	10270	11060	13800	13020	11637	12710	17312	21820	11472
1911	3636	2999	1439	2071	5952	6488	6905	4525	4506	7266	12764	4042	5216
1912	1351	992	482	356	2692	4346	5371	6700	7622	10190	14067	5335	4959
1913	2583	1298	678	567	4992	5112	5369	6896	7292	8859	15317	4307	5272
1914	1739	744	167	308	3219	5785	1898	4920	9841	14752	11154	7010	5128
Mean 25 Yr	5626	2447	1481	2123	5971	6466	8028	[illegible]	9175	11022	14090	11253	7214

January 1890 to April 1907 from (Bohio Discharge) x (1.62).
May 1907 to April 1908 from (Bohio+Trinidad+Gatun River) x (1.10).

TABLE 36.

DISCHARGE TABLE

GATUN

Cubic Feet per Second per Square Mile.

Watershed Area - 1320 Square Miles.

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1890	5.07	1.91	1.56	1.52	8.05	10.06	10.19	10.74	12.88	12.20	7.46	11.14	7.73
1891	3.29	1.69	0.74	0.74	6.54	3.95	5.90	5.55	5.72	8.40	14.13	9.67	5.52
1892	2.86	1.56	1.43	2.90	10.40	6.68	14.00	11.49	8.28	11.17	13.66	11.48	7.99
1893	4.34	2.86	1.78	4.20	5.72	6.07	9.36	13.22	9.41	10.53	14.05	22.72	8.68
1894	8.67	2.21	1.28	0.95	4.12	5.25	7.63	7.98	9.14	11.49	15.61	15.43	7.48
1895	5.59	1.69	1.30	1.30	5.11	5.29	5.64	8.49	7.11	8.49	7.46	8.54	5.50
1896	5.81	1.91	1.08	2.08	6.07	5.16	3.86	4.29	7.28	7.80	9.32	7.42	5.17
1897	2.51	1.95	0.87	1.08	9.80	5.16	6.28	8.93	8.45	9.19	8.54	8.36	5.93
1898	6.93	2.08	1.34	2.47	3.29	4.12	8.06	6.50	3.95	6.20	9.62	3.51	4.84
1899	4.72	2.12	1.21	1.34	2.51	3.86	4.86	7.02	5.20	6.07	6.50	4.42	4.15
1900	2.60	1.30	0.91	0.87	2.00	3.51	6.89	6.46	5.86	8.58	8.10	4.60	4.31
1901	1.82	1.21	0.87	0.69	2.82	3.43	3.90	5.29	7.11	7.76	16.26	5.64	4.73
1902	13.78	2.56	1.56	2.64	3.27	3.90	3.73	4.16	4.81	7.28	8.19	3.69	4.96
1903	1.99	1.26	0.78	0.69	1.86	3.12	4.94	6.72	6.98	6.84	10.23	12.88	4.86
1904	6.07	2.86	1.73	4.46	3.72	5.80	5.54	3.89	8.18	6.02	9.34	5.06	5.22
1905	2.38	1.21	0.87	0.73	3.46	3.25	2.34	4.76	4.85	8.52	5.80	3.50	3.47
1906	1.64	1.06	0.75	1.23	2.64	3.27	6.42	7.78	6.69	5.00	9.58	13.07	4.93
1907	4.09	1.71	1.23	0.83	2.27	4.48	5.40	4.50	6.82	10.21	7.04	4.24	4.40
1908	1.50	0.79	0.64	0.68	3.82	3.81	4.35	6.73	6.60	6.72	10.91	6.08	4.38
1909	4.93	3.98	1.63	1.68	3.19	7.48	7.52	8.32	7.51	9.54	21.58	19.55	8.07
1910	8.90	3.85	2.39	4.61	7.78	8.38	10.45	9.86	8.82	9.63	13.11	16.53	8.69
1911	2.75	2.27	1.09	1.57	4.51	4.92	5.23	3.43	3.41	5.50	9.67	3.06	3.95
1912	1.02	0.75	0.36	0.27	2.04	3.29	4.07	5.08	5.77	7.72	10.66	4.04	3.76
1913	1.96	0.89	0.51	0.43	3.78	3.87	4.07	5.22	5.52	6.71	11.60	3.26	3.99
1914	1.32	0.56	0.13	0.23	2.44	4.38	1.44	3.73	7.46	11.18	8.45	5.31	3.89
Mean 25 Yr	4.26	1.85	1.12	1.61	4.45	4.90	6.08	6.06	6.95	8.35	10.68	8.53	5.46

TABLE 37

DISCHARGE TABLE

GATUN

Inches on Watershed

Watershed Area - 1320 Square Miles.

Year	Jan.	Feb.	Mar.	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Annual total
1890	5.845	1.989	1.799	1.696	9.281	11.226	11.748	12.384	14.368	14.070	8.323	12.844	105.573
1891	3.793	1.760	.853	.826	7.540	4.407	6.802	6.399	6.382	9.684	15.763	11.148	75.357
1892	3.297	1.682	1.649	3.236	11.990	7.453	16.140	13.248	9.238	12.877	15.242	13.236	109.288
1893	5.004	2.978	2.052	4.686	6.595	6.772	10.791	15.242	10.499	12.143	15.675	26.194	118.631
1894	9.996	2.301	1.476	1.060	4.750	5.857	8.797	9.200	10.197	13.248	17.412	17.786	102.080
1895	6.445	1.760	1.499	1.450	5.891	5.902	6.502	9.788	7.933	9.788	8.323	9.846	75.127
1896	6.698	2.060	1.245	2.321	6.998	5.757	4.450	4.946	8.122	8.993	10.398	8.554	70.542
1897	2.894	2.031	1.003	1.205	11.298	5.757	7.240	10.295	9.428	10.595	9.528	9.638	80.912
1898	7.990	2.166	1.545	2.756	3.793	4.597	9.292	7.494	4.407	7.148	10.733	4.047	65.968
1899	5.442	2.197	1.395	1.495	2.894	4.307	5.603	8.093	5.802	6.998	7.252	5.096	56.574
1900	2.998	1.354	1.049	.971	2.306	3.916	7.943	7.448	6.538	9.892	9.037	5.303	58.755
1901	2.098	1.260	1.003	.770	3.251	3.827	4.496	6.099	7.933	8.946	18.142	6.502	64.327
1902	15.886	2.666	1.79[illegible]	2.945	3.770	4.361	4.300	4.796	5.367	8.393	9.138	4.254	67.665
1903	2.294	1.312	.899	.770	2.144	3.481	5.695	7.747	7.788	7.886	11.413	14.846	66.277
1904	6.998	3.085	1.994	4.976	4.289	6.471	6.387	4.485	9.126	6.940	10.421	5.834	71.006
1905	2.744	1.260	1.003	.814	3.989	3.626	2.698	5.488	5.411	9.823	6.471	4.035	47.362
1906	1.891	1.104	.865	1.372	3.044	3.648	7.402	8.969	7.464	5.764	10.688	15.067	67.280
1907	4.715	1.781	1.418	.926	2.617	4.998	6.226	5.188	7.609	11.771	7.855	4.888	59.992
1908	1.729	.852	.738	.759	4.404	4.251	5.015	7.759	7.364	7.747	12.171	7.010	59.799
1909	5.684	4.144	1.879	1.874	3.678	8.345	8.670	9.592	8.379	10.999	24.078	22.540	109.862
1910	10.261	4.009	2.755	5.143	8.969	9.350	12.050	11.367	9.840	11.102	14.631	19.056	118.533
1911	3.170	2.364	1.257	1.752	5.200	5.489	6.030	3.954	3.805	6.341	10.789	3.528	53.679
1912	1.176	.810	.421	.301	2.352	3.671	4.692	5.851	6.438	8.900	11.693	4.658	51.163
1913	2.260	1.024	.593	.480	4.358	4.318	4.692	6.018	6.159	7.736	12.942	3.758	54.338
1914	1.620	.587	.145	.257	2.813	4.887	1.660	4.300	8.323	12.889	9.428	6.122	52.931
Mean 25 Yr	4.913	1.941	1.293	1.793	5.129	5.466	7.013	7.846	7.757	9.627	11.910	9.832	74.521

TABLE 38.

D I S C H A R G E   T A B L E S

T R I N I D A D   R I V E R

(Above Largartera Station, Watershed Area = 314 Sq. Mi.)

Cubic Feet per Second

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1907					556	1097	985	845	1334	3144	2076	1135	
1908	356	166	131	105	946	1118	1027	1939	1853	1825	2359	1631	1123
1909	1398	988	365	210	782	1870	1760	2155	1940	2580	2660	2470	1598
1910	1940	840	565	1250	1880	1980	2000	1500	1900	2000	2500	2200	1713
1911	1000	300	170	190									
Means (4Yr.)	1174	578	308	439	1041	1516	1443	1610	1757	2387	2399	1859	1376

Cubic Feet per Second per Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1907					1.77	3.49	3.14	2.69	4.25	10.02	6.49	3.61	
1908	1.13	.59	.42	.33	3.01	3.56	3.27	6.18	5.90	5.81	7.51	5.19	3.58
1909	4.45	3.15	1.16	.67	2.49	5.96	5.60	6.86	6.18	8.22	8.47	7.87	5.09
1910	6.18	2.67	1.80	3.98	5.99	6.31	6.37	4.78	6.05	6.37	7.96	7.01	5.46
1911	3.18	.96	.54	.60									
Means (4Yr)	3.74	1.84	.98	1.40	3.32	4.83	4.60	5.13	5.60	7.60	7.61	5.92	4.38

Inches on Watershed

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total.
1907					2.041	3.894	3.620	3.101	4.742	11.552	7.241	4.162	
1908	1.303	.636	.484	.368	3.470	3.972	3.770	7.125	6.583	6.698	8.379	5.983	48.771
1909	5.130	3.280	1.337	.748	2.871	6.650	6.456	7.909	6.895	9.477	9.450	9.073	69.276
1910	7.125	2.780	2.075	4.440	6.906	7.040	7.344	5.511	6.750	7.344	8.881	8.082	74.278
1911	3.666	1.000	.623	.669									
Means (4Yr)	4.306	1.924	1.130	1.556	3.822	5.389	5.298	5.912	6.242	8.768	8.488	6.825	59.660

TABLE 39.

D I S C H A R G E   T A B L E S

G A T U N   R I V E R

(Above Monte Lirio-old station, Watershed Area = 127 Sq. Mi.)

Cubic Feet per Second

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1907					315	622	839	604	1183	1268	935	600	
1908	159	84	57	40	533	460	708	788	675	983	1821	627	578
1909	615	470	157	114	454	1170	848	780	930	1160	2450	2600	979
1910	805	440	270	550	950	1140	1400	1300	1160	1290	1600	2500	1117
Means (3&4Yr)	526	331	161	235	563	848	949	868	987	1175	1702	1582	827

Cubic Feet per Second per Sq. Mi.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1907					2.48	4.90	6.61	4.76	9.32	9.97	7.37	4.72	
1908	1.25	.66	.45	.32	4.20	3.62	5.58	6.21	5.32	7.74	14.34	4.94	4.55
1909	4.84	3.70	1.24	.90	3.58	9.21	6.68	6.15	7.33	9.13	19.30	20.46	7.71
1910	6.34	3.47	2.12	4.33	7.48	8.97	11.02	10.23	9.13	10.15	12.60	19.68	8.79
Means (3&4Yr)	4.14	2.61	1.27	1.85	4.44	6.68	7.47	6.84	7.78	9.25	13.40	12.45	6.52

Inches on Watershed

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total6
1907					2.859	5.467	7.621	5.488	10.398	11.494	8.223	5.442	
1908	1.441	.712	.519	.357	4,842	4.039	6.433	7.159	5.936	8.923	15.998	5.695	62.054
1909	5.580	3.853	1.450	1.004	4.127	10.276	7.701	7.090	8.178	10.526	21.530	23.586	104.881
1910	7.309	3.613	2.444	4.831	8.624	10.008	12.704	11.793	10.186	11.700	14.060	22.688	119.960
Means (3&4Yr)	4.777	2.726	1.464	2.064	5.115	7.448	8.615	7.882	8.674	10.661	14.953	14.353	88.730

TABLE 40.

DISCHARGE OF CHAGRES RIVER, 25 YRS. RECORD

1890 to 1914, Incls.

ALHAJUELA-Drainage Area

427 Sq. Mi.

MONTH	Mean Monthly Discharge For 25 Years			Maximum Year, 1909 Monthly Discharge			Maximum Year, 1909 Accumulated Discharge			Minimum Year, 1905 Monthly Discharge			Minimum Year, 1905 Accumulated Discharge			Minimum Dry Season, 1912 Monthly Discharge			Minimum Dry Season, 1912 Accumulated Discharge		
	Total C.F.S.	C.F.S. per sq. mile.	Inches run-off	C.F.S.	C.F.S. per sq. mile.	Inches run-off	Billions of cu. ft.	Billions of cu.ft. sq. mi	Inches run-off	C.F.S.	C.F.S. per sq. mile	Inches run-off	Billions of cu. ft.	Billions of cu.ft. sq. mi.	Inches run-off	C.F.S.	C.F.S. per sq. mile	Inches run-off	Billions of cu. ft.	Billions of cu.ft. sq. mi.	Inches run-off
January	2,178	5.102	5.962	4,040	9.46	10.906	10.821	.0253	10.906	1,413	3.32	3.828	3.798	.0089	3.828	734	1.72	1.983	1.97	.0046	1.963
February	1,223	2.864	2.999	3,315	7.78	8.101	18.840	.0442	19.007	777	1.82	1.895	5.678	.0133	5.723	516	1.21	1.305	3.26	.0076	3.288
March	743	1.738	2.003	1,155	2.72	3.136	21.934	.0570	22.143	578	1.35	1.556	7.226	.0169	7.279	382	.89	1.031	4.28	.0100	4.319
April	1,052	2.466	2.751	1,110	2.60	2.901	24.811	.0581	25.044	442	1.04	1.160	8.371	.0196	8.439	371	.87	.970	5.24	.0123	5.289
May	2,227	5.214	6.012	2,420	5.67	6,537	31.293	.0733	31.581	1,932	4.53	5.223	13.546	.0318	13,662	1,682	3.94	4.542	9.75	.0228	9.831
June	2,332	5.459	6.090	4,370	11.41	12.731	43.916	.1029	44.312	1,594	3.73	4.162	17.678	.0414	17.824	1,857	4.35	4.353	14.56	.0341	14.664
July	2,823	6.611	7.622	3,300	7.73	8.912	52.755	.1236	53.224	1,248	2.92	3.366	21.020	.0492	21.190	2,592	6.07	6.998	21.50	.0504	21.682
August	2,946	6.899	7.953	4,090	9.58	11.045	63.710	.1493	64.269	2,207	5.17	5.960	26.932	.0631	27.150	2,580	6.04	6.963	28.41	.0666	28.645
September ...	2,935	6.874	7.670	3,560	8.34	9.305	72.937	.1710	73.574	1,722	4.04	4.507	31.395	.0735	31.657	2,853	6.68	7.453	35.80	.0838	36.093
October	3,256	7.624	8.790	3,665	8.57	9.880	82.753	.1938	83.454	2,688	6.30	7.263	38.595	.0903	38.920	3,040	7.12	8.209	43.94	.1029	44.307
November	4,311	10.100	11.266	11,300	26.48	29.546	112.043	.2627	113.010	2,267	5.31	5.924	44.471	.1042	44.844	5,541	12.98	14.432	58.31	.1366	58.730
December	4,253	9.960	11.483	17,300	40.55	46.750	158.379	.3720	159.759	1,265	2.96	3.413	47.856	.1121	48.257	3,058	7.16	8.255	66.50	.1557	67.044
Mean	2,523	5.909	6.710	5,010	11.74	13.313	....	.....	....	1,512	3.54	4.021	......	.....	......	2,100	4.92	5.587	....	.....	......
Average for 4 dry mos. ...	1,299	3.042	3.409	2,405	5.64	6.261	....	.....	....	804	1.88	2.110	......	.....	......	501	1.17	1.322	.....	.....	......
Average for 8 wet mos. ...	3,135	7.343	8.361	6,313	14.79	16.838	....	.....	....	1,865	4.37	4.977	......	.....	......	2,900	6.79	7.719	.....	.....	......

TABLE 41.

BOHIO--DRAINAGE AREA 779 Square Miles.
(Discharge Measurements Discontinued Dec. 1910.)

MONTH.	Mean Monthly Discharge: For 21 years. Total C.F.S.	C.F.S. per sq. mile.	Inches run-off	Maximum Year, 1909. Monthly Discharge. C.F.S.	C.F.S. per sq. mile.	Inches run-off	Accumulated Discharge. Billions of cu. ft.	Billions of cu.ft. sq. mi.	Inches run-off	Minimum Year, 1905. Monthly Discharge. C.F.S.	C.F.S. per sq. mile.	Inches run-off	Accumulated Discharge. Billions of cu. ft.	Billions of cu.ft. sq. mi.	Inches run-off	Minimum Dry Season, 1908. Monthly Discharge. C. F.S.	C.F.S. per sq. mile.	Inches run-off.	Accumulated Discharge. Billions of cu. ft.	Billions of cu.ft. sq. mi.	Inches run-off.
January	3,830	4.92	5,672	4,390	5.64	6,502	11,758	.0151	6,502	1,942	2.49	2,871	5,201	.0067	2,871	1,281	1.64	1,891	3,431	.0043	1,891
February	1.627	2.09	2,176	3,580	4.60	4,790	20,419	.0262	11,292	989	1.27	1,322	7,594	.0097	4,103	681	0.87	0,938	5,078	.0065	2,829
March	1,064	1.37	1.579	1,325	1.70	1,960	23,968	.0307	13,252	706	0.91	1,049	9,485	.0122	5,242	586	0.75	0,865	6,648	.0085	3,694
April	1,361	1.75	1,952	1.195	1.52	1,696	27,039	.0347	14.948	600	0.77	0,859	11,040	.0142	6,101	666	0.86	0,960	8,374	.0108	4,654
May	3,842	4.93	5,664	3,225	4.14	4,773	35,677	.0458	19,721	2,825	3.63	4,185	18,607	.0239	10,286	3,894	5.00	5,764	18,804	.0243	10,418
June	4,139	5.28	5,891	7.010	9.00	10,041	53,847	.0692	29,762	2,649	3.40	3,793	25,473	.0327	14,079	3,131	4.02	4,485	26,320	.0345	14,903
July	5,229	6.72	7,747	5,630	7.23	8,335	68,926	.0884	38,097	1,907	2.45	2,825	30,580	.0395	16,904	3,626	4.65	5,361	36,632	.0470	20,264
August	5,994	7.69	8,966	6,600	8.47	9,765	86,604	.1112	47,862	3,884	4.98	5,741	40,984	.0526	22,645	5,491	7.04	8,116	51,338	.0659	28,380
September	5,912	7.58	8.457	5,550	7.12	7,944	100,989	.1295	55,606	3,355	5.08	5,668	51,236	.0657	28,313	5,599	7.18	8,011	65,850	.0845	36,391
October	6,900	8.86	10,215	8,230	10.57	12,187	123,033	.1578	67,993	6,957	8.93	10,295	69,869	.0898	38,608	5,558	7.13	8,220	80,738	.1036	44,611
November	*8,900	11.42	12.742	21,380	27.45	30,625	178,450	.2290	98,613	4,732	6.08	6,783	82.135	.1055	45,391	9,515	12.22	13,632	105,400	.1353	58,243
December	*7,569	9.72	11,206	19,800	25.42	29,304	231,482	.2971	127,922	2,860	3.67	4,231	89,795	.1153	49,622	5,046	6.48	7,471	118.918	.1527	65,714
Mean	4,701	6.03	6,949	7,325	9.40	10,660	....	....	....	2,834	3.64	4,135	....	....	....	3,756	4.82	5.476	....	....	....
Average for 4 dry months.	1,970	2.53	2,845	2,620	3.36	3,737	....	....	....	1,059	1.36	1,525	....	....	....	804	1.03	1,164	....	....	....
Average for 8 wet months.	6,069	7.78	8,851	9,678	12.42	14,122	....	....	....	3,721	4.78	5,440	....	....	....	5,232	6.72	7,632	....	....	....

*1890-1909, inclusive

TABLE 42.

DISCHARGE OF CHAGRES RIVER - 25 YEARS OF RECORD

GATUN — DRAINAGE AREA, 1320 SQ. MILES

- - - - - - - - - -

MONTH	Mean Monthly Discharge For 25 Years			Maximum Year, 1910						Minimum Year, 1905						Minimum Dry Season, 1912					
				Monthly Discharge			Accumulated Discharge			Monthly Discharge			Accumulated Discharge			Monthly Discharge			Accumulated Discharge		
	Total C.F.S.	C.F.S. per sq mile	Inches Run-off	C.F.S.	C.F.S. per sq. mile	Inches Runoff	Billions of cu.ft.	Billions of cu ft sq.mi.	Inches Run-off.	C.F.S.	C.F.S. per sq. mile	Inches Run-off	Billions of cu. ft.	Billions of cu ft sq.mi.	Inches Run-off	C.F.S.	C.F.S. per sq. mile	Inches Run-off	Billions of cu. ft.	Billions of cu ft sq. mi.	Inches Run-off
January....	5,626	4.262	4.913	11,740	8.90	10.261	31.444	.0238	10.261	3,140	2.38	2.744	8.410	.0064	2.744	1,351	1.02	1.176	3.61	.0027	1.176
February...	2,447	1.849	1.940	5,080	3.85	4.009	43.734	.0331	14.270	1,599	1.21	1.260	12.278	.0093	4.004	992	.75	.810	6.09	.0046	1.986
March......	1,481	1.122	1.293	3,160	2.39	2.755	52.198	.0396	17.025	1,142	0.86	0.992	15.337	.0116	4.996	482	.36	.421	7.38	.0056	2.407
April......	2,123	1.608	1.793	4,560	3.45	3.849	64.017	.0485	20.874	970	0.73	0.814	17.851	.0135	5.810	356	.27	.301	8.30	.0063	2.708
May	5,971	4.524	5.216	10,270	7.78	8.969	91.524	.0693	29.843	4,568	3.46	3.989	30.086	.0228	9.799	2,692	2.04	2.352	15.51	.0118	5.060
June	6,466	4.900	5.466	11,060	8.38	9.350	120.192	.0910	39.193	4,283	3.24	3.615	41.188	.0312	13.414	4,346	3.29	3.671	26.77	.0203	8.731
July	8,028	6.083	7.013	13,800	10.45	12.050	157.154	.1191	51.243	3,083	2.33	2.686	50.445	.0383	16.100	5,371	4.07	4.692	41.16	.0312	13.423
August ...	8,984	6.806	7.847	13,020	9.86	11.367	192.027	.1454	62.610	6,283	4.76	5.488	67.274	.0509	21.588	6,700	5.08	5.851	59.10	.0448	19.274
September	9,175	6.952	7.757	11,637	8.82	9.840	222.190	.1684	72.450	6,395	4.84	5.400	83.850	.0635	26.988	7,622	5.77	6.438	78.85	.0597	25.712
October ..	11,022	8.350	9.627	12,710	9.63	11.091	256.232	.1941	83.541	11,250	8.52	9.823	113.982	.0863	36.811	10,190	7.72	8.900	106.15	.0804	34.612
November .	14,090	10.675	11.910	17,312	13.11	14.631	301.105	.2280	98.172	7,652	5.80	6.471	133.816	.1010	43.282	14,076	10.66	11.893	142.63	.1080	46.505
December .	11,262	8.852	9.832	21,820	16.53	19.056	359.548	.2730	117.228	4,624	3.51	4.047	146.201	.1107	47.329	5,335	4.04	4.658	156.92	.1189	51.163
Mean....	7,222	5.472	6.217	11,347	8.60	9.769				4,582	3.47	3.944				4,959	3.76	4.264			
Average for: 4 dry mo's	2,919	2.210	2.485	6,135	4.65	5.218				1,713	1.29	1.452				795	.60	.677			
Average for: 8 wet mo's	9,375	7.143	8.084	13,954	10.57	12.044				6,017	4.58	5.190				7,041	5.34	6.057			

N O T E : Four dry months — January, February, March and April.

TABLE 43.

RUN-OFF past GATUN

ARRANGED IN PERIODS OF MAXIMUM FLOW

Period	Date of Period - (Inc).	Discharge - c.f.s.
1 month	December, 1893	30037
2 months	November 1 to December 31, 1909	27135
~~3 months~~	October 1 to December 31, 1909	22287
4 months	October 1, 1909 to January 31, 1910	19650
5 months	August 1 to December 31, 1893	18470
6 months	July 1 to December 31, 1893	17460
7 months	July 1, 1893 to January 31, 1894	16600
8 months	June 1, 1893 to January 31, 1894	15520
9 months	May 1, 1893 to January 31, 1894	14650
10 months	April 1, 1893 to January 31, 1894	13740
11 months	April 1, 1893 to February 28, 1894	12743
1 year	February 1, 1893 to January 31, 1894	11948
2 years	March 1, 1892 to February 28, 1894	11366
3 years	March 1, 1892 to February 28, 1895	10736
4 years	November 1, 1891 to October 31, 1895	10003
5 years	February 1, 1890 to January 31, 1895	9890
6 years	March 1, 1890 to February 29, 1896	9460
7 years	January 1, 1890 to December 31, 1896	9070
8 years	May 1, 1890 to April 30, 1898	8940
9 years	January 1, 1890 to December 31, 1898	8632
10 years	January 1, 1890 to December 31, 1899	8318
11 years	January 1, 1890 to December 31, 1900	8080
12 years	May 1, 1890 to April 30, 1902	8020
13 years	January 1, 1890 to December 31, 1902	7840
14 years	May 1, 1890 to April 30, 1904	7780
15 years	January 1, 1890 to December 31, 1904	7680
16 years	January 1, 1890 to December 31, 1905	7470
17 years	January 1, 1890 to December 31, 1906	7414
18 years	January 1, 1890 to December 31, 1907	7340
19 years	January 1, 1892 to December 31, 1910	7481
20 years	January 1, 1891 to December 31, 1910	7472
21 years	January 1, 1890 to December 31, 1910	7602.

TABLE 44.

RUN-OFF past GATUN

ARRANGED IN PERIODS OF MINIMUM FLOW.

Periods	Date of Period (Incl.)	Discharge - c.f.s.
1 Month	March, 1908	851
2 Months	March 1 to April 30, 1908	872
3 Months	February 1 to April 30, 1908	930
4 Months	January 1 to April 30, 1908	1191
5 Months	January 1 to May 31, 1903	1739
6 Months	January 1 to June 30, 1903	2136
7 Months	December 1, 1902 to June 30, 1903	2526
8 Months	December 1, 1902 to July 31, 1903	3025
9 Months	January 1, 1905 to September 30, 1905	3486
10 Months	December 1, 1904 to September 30, 1905	3814
11 Months	July 1, 1905 to May 31, 1906	4419
1 Year	June 1, 1905 to May 31, 1906	4435
2 Years	September 1, 1899 to August 31, 1901	5163
3 Years	September 1, 1898 to August 31, 1901	5310
4 Years	August 1, 1904 to July 31, 1908	5544
5 Years	August 1, 1898 to July 31, 1903	5815
6 Years	July 1, 1902 to June 30, 1898	5823
7 Years	July 1, 1899 to June 30, 1906	5928
8 Years	August 1, 1898 to July 31, 1906	5902
9 Years	May 1, 1899 to April 30, 1908	5972
10 Years	August 1, 1898 to July 31, 1908	5937
11 Years	February 1, 1898 to January 31, 1909	6032
12 Years	July 1, 1896 to June 30, 1908	6255
13 Years	November 1, 1895 to October 31, 1908	6239
14 Years	February 1, 1895 to January 31, 1909	6314
15 Years	February 1, 1894 to January 31, 1909	6749
16 Years	November 1, 1893 to October 31, 1909	6769
17 Years	November 1, 1892 to October 31, 1909	6970
18 Years	January 1, 1891 to December 31, 1908	7092
19 Years	November 1, 1890 to October 31, 1909	7139
20 Years	November 1, 1890 to October 31, 1910	7411
21 Years	January 1, 1890 to December 31, 1910	7602.

TABLE 45.

CHAGRES RIVER DRAINAGE BASIN

Maximum Rates of Run-Off During Freshets Beginning Dec. 26, 1909, and Feb. 12, 1911.

DISCHARGE - Cubic feet per second. HEIGHT - Elevation above Mean Sea Level.

ALHAJUELA Drainage Area - 427 Square Miles					BOHIO Drainage Area - 779 Square Miles					GATUN Drainage Area - 1,320 Square Miles				
Date	Time	Height	Momentary Rate of Discharge	24 Hour Rate of Discharge	Date	Time	Height	Momentary Rate of Discharge	24 Hour Rate of Discharge	Date	Time	Height	Momentary Rate of Run-off: Storage + Discharge	24 Hour Rate of Run-off Storage + Discharge
December 26, 1909	7 PM	121.00	170,000	95,700	December 27	11 AM	38.7	90,000	78,400	December 28	9 AM	19.65	124,000	94,000
December 30, 1909	11 AM	112.00	97,200	43,500	December 31	2 AM	32.1	58,500	38,600	December 31	9 AM	17.7	60,000	57,000
February 12, 1911	11 PM	105.50	43,600	17,280	February 13	10 AM	21.1	37,500	.....	February 13	4 PM	15.7	38,860	21,520

The second class includes areas which, while not uniformly precipitous, are rolling, and are cut by numerous streams or ravines.

The third class includes flat land having little or no appreciable slope. Aside from the general topography, the condition of the ground surface has much to do with the rate of run-off. A clean hard surface, over which the water can find its way without difficulty, filled with gullies and small channels, will have a quicker run-off than a surface covered with vegetation, loose rock and heavy timber, and having no well-defined channels for carrying water. Large watersheds may be counted on to have a lower rate of run-off than smaller ones, as most extreme storms are local. This localization of extreme rainfalls is so general that it may be depended on in calculating run-offs of very large areas. In a large watershed local conditions may be depended upon to counterbalance each other. A small area may combine many elements which tend to produce a large run-off, while in large areas some parts will have a larger run-off than others, and the whole area will have less than that portion having the more extreme condition, and the run-off of the various parts will never coincide exactly in point of time. The water falling nearest the outlet will pass away before that from a distance, and so the flood flow will be modified.

The shape and location of a watershed also affect the rate of run-off. A drainage area having a fan-shaped outline, with numerous tributary channels uniting to form an outlet at the small end of the fan, will have a comparatively high rate of run-off, because water from the greater part of the area will be concentrated in the main channel. In a long, narrow drainage area the flow will be distributed over a larger time, on account of difference of time required for water in different parts to reach the outlet.

Evaporation.

One of the most important factors to be considered in the hydrology of a watershed is evaporation, as practically all the water falling upon a drainage area either passes out of the district in its water courses, or is evaporated.

On the Isthmus of Panama the rate of evaporation is very much greater in the dry season than in the wet, in windy than in

calm weather, and more rapid from exposed surfaces than from those which are sheltered.

A great deal of water is taken from the soil by plants and is evaporated from their leaves. Only the most general knowledge of this subject is available.

In addition to the amount of water taken from the soil and evaporated through the leaves of trees and rank vegetation, a considerable amount of the light rains, variously estimated from 20% to 50%, never reaches the soil, but, being caught by the leaves, is again evaporated.

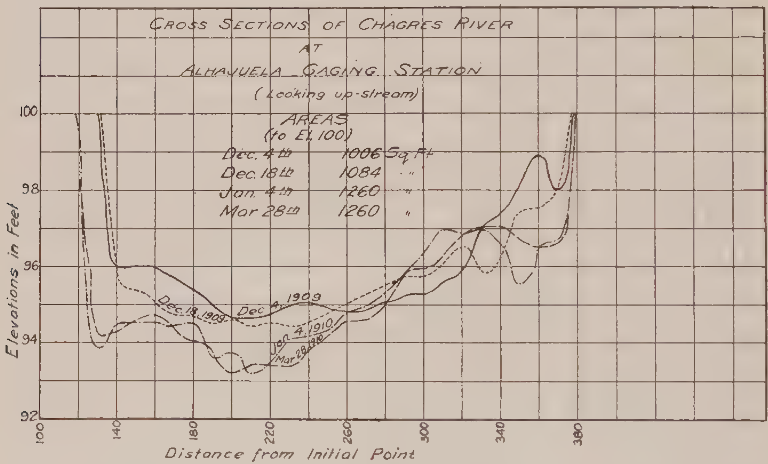


Fig. 22.

Tables 26 to 37, inclusive, give the discharge measurements in various units for the Chagres River at Alhajuela, Gamboa, Bohio, and Gatun. Unless otherwise noted, the quantities are from actual gaging, by floats previous to 1907, except in 1899 and 1900, and subsequently by current meter work.

Similar data for years of record are given in Tables 38 and 39 for the Trinidad and Gatun rivers. The cross sections shown by Figs. 22 to 24, inclusive, are characteristic of the variations in area due to freshet scouring.

Cross sections taken on December 18, 1909, and January 4, 1910, as shown in Fig. 22, taken before and after one of the largest freshets on the river, illustrate graphically the change in area due to freshet scour.

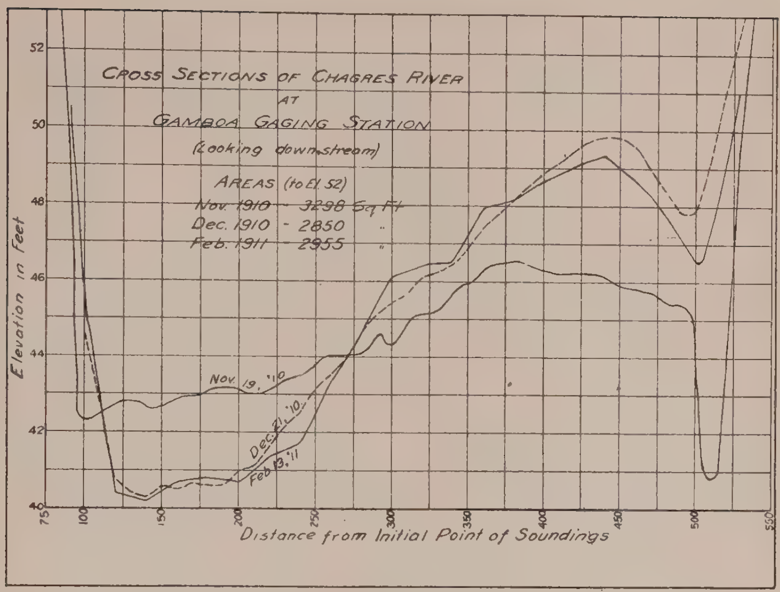

CROSS SECTIONS OF CHAGRES RIVER
AT
GAMBOA GAGING STATION
(Looking down stream)
AREAS (to El. 52)
Nov. 1910 - 3298 Sq. Ft.
Dec. 1910 - 2850 "
Feb. 1911 - 2955 "
Nov. 19, '10
Dec. 21, '10
Feb. 13, '11
Elevation in Feet
52
50
48
46
44
42
40
75
100
150
200
250
300
350
400
450
500
550
Distance from Initial Point of Soundings

Fig. 23.

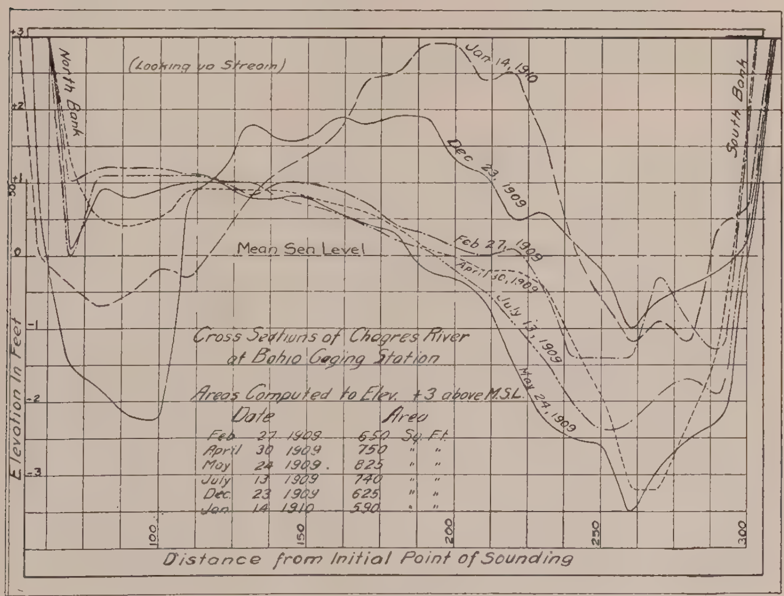

(Looking up Stream)
North Bank
South Bank
Jan 14, 1910
Dec 23, 1909
Feb 27, 1909
April 30, 1909
July 13, 1909
May 24, 1909
Mean Sea Level
Cross Sections of Chagres River
at Bohio Gaging Station
Areas Computed to Elev. +3 above M.S.L.
Date Area
Feb 27 1909 650 Sq. Ft.
April 30 1909 750 " "
May 24 1909 825 " "
July 13 1909 740 " "
Dec. 23 1909 625 " "
Jan 14 1910 590 " "
Elevation in Feet
+3
+2
+1
0
-1
-2
-3
100
150
200
250
300
Distance from Initial Point of Sounding

Fig. 24.

Figure 25 best illustrates the relation of change in area, velocity, and discharge. The change in cross section producing the change in discharge can be seen by the inspection of Fig. 23.

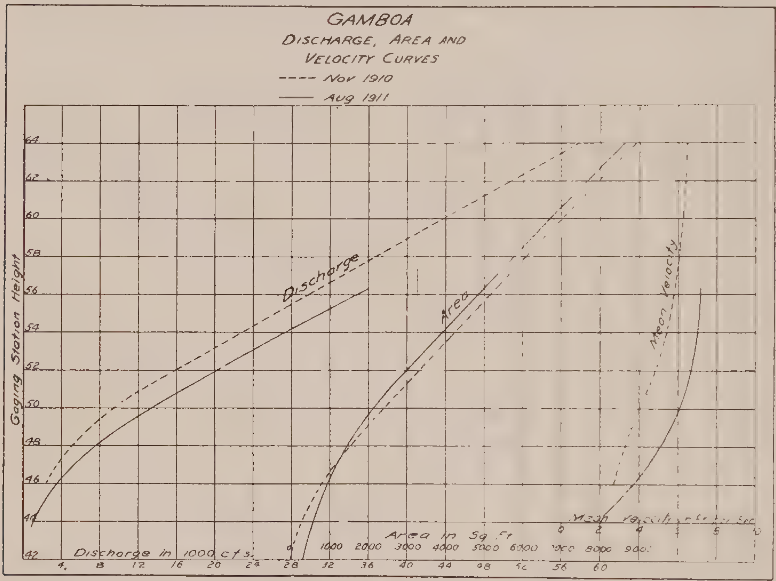


Fig. 25.

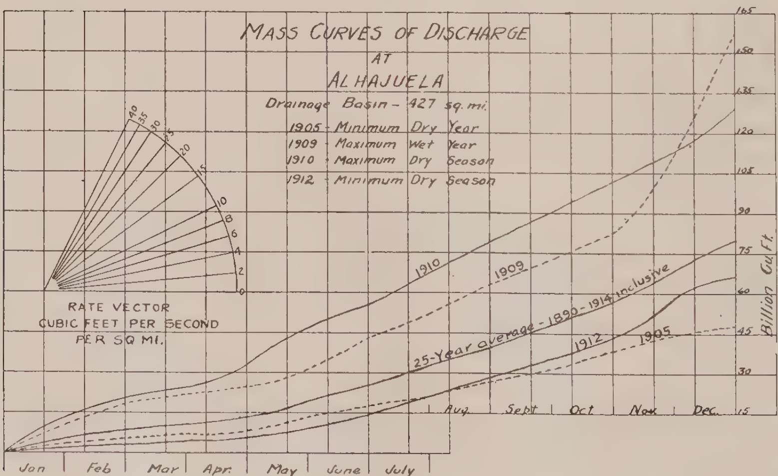


Fig. 26.

Tables 40 to 42, inclusive, give the discharge measurements in various units for the Chagres River for years of record, at Alhajuela, Bohio, and Gatun, and give specifically the mean monthly, maximum year, minimum year, and minimum dry season.

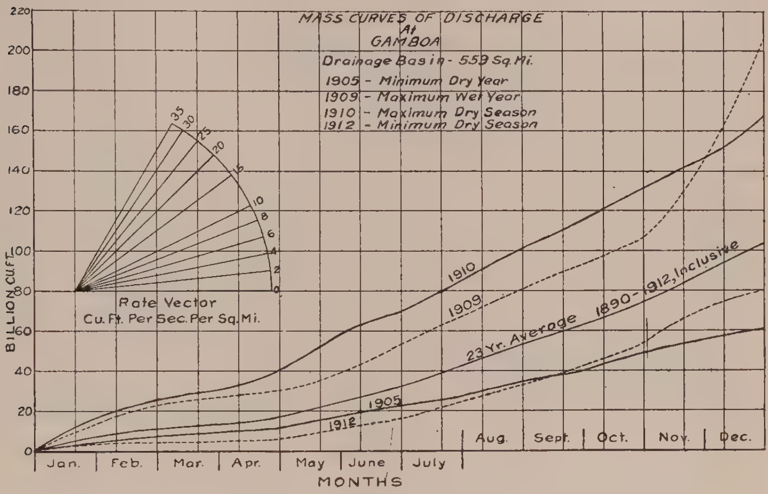


Fig. 27.

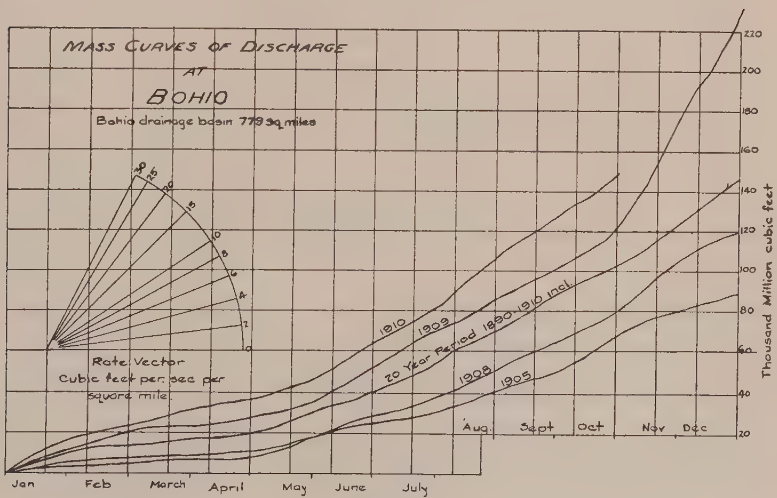


Fig. 28.

The minimum year of run-off was 1905 at all stations, and the minimum dry season run-off was 1912. Previous dry season run-off was during 1908.

The calendar year 1909 was the calendar year of maximum run-off at all stations except Gatun, which had its maximum in 1910.

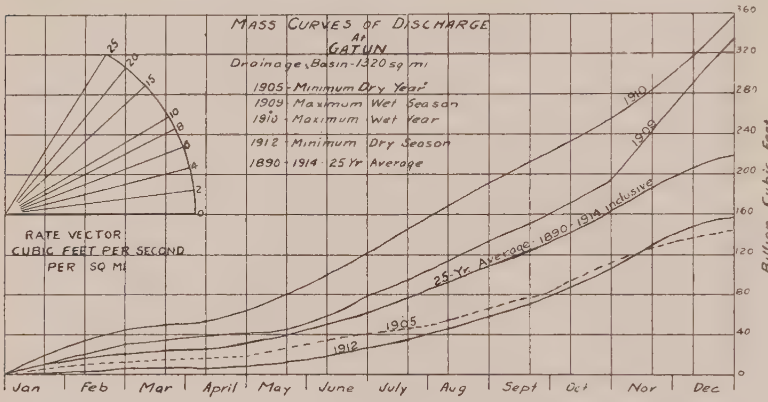


Fig. 29.

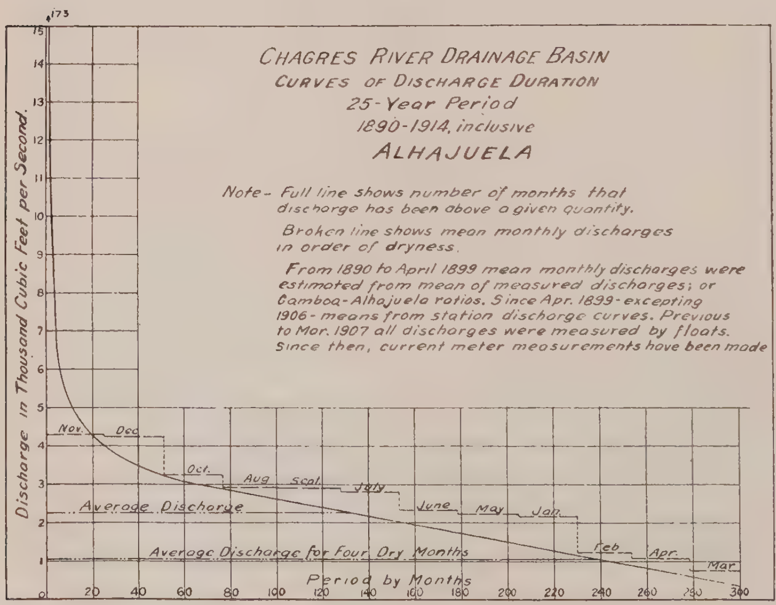
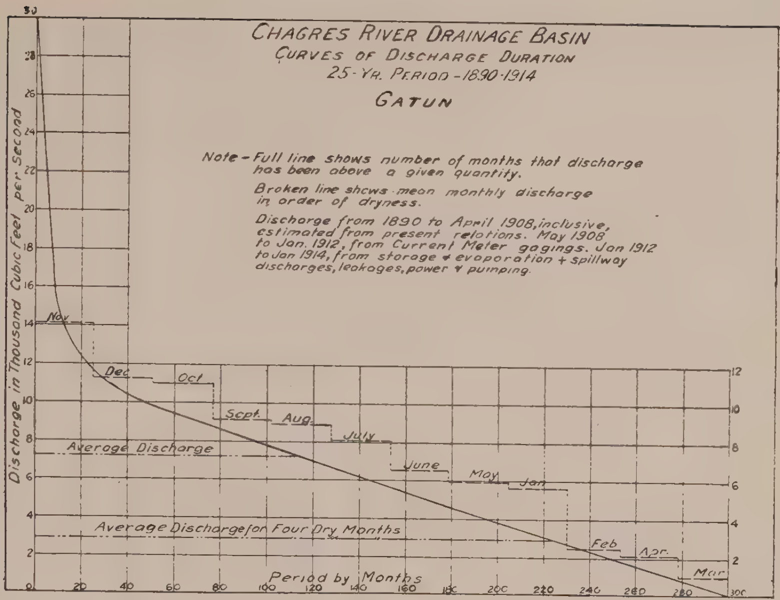
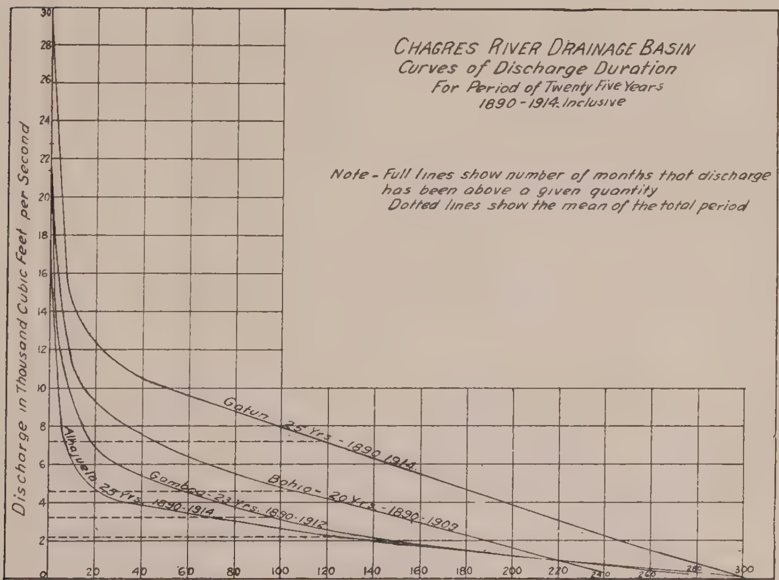


Fig. 30.



CHAGRES RIVER DRAINAGE BASIN
CURVES OF DISCHARGE DURATION
25-YR. PERIOD -1890-1914
GATUN
Note - Full line shows number of months that discharge has been above a given quantity.
Broken line shows mean monthly discharge in order of dryness.
Discharge from 1890 to April 1908, inclusive, estimated from present relations. May 1908 to Jan. 1912, from Current Meter gagings. Jan 1912 to Jan 1914, from storage + evaporation + spillway discharges, leakages, power + pumping.
Discharge in Thousand Cubic Feet per Second
Nov
Dec
Oct
Sept.
Aug.
July
June
May
Jan
Feb
Apr.
Mar
Average Discharge
Average Discharge for Four Dry Months
Period by Months

Fig. 31.



CHAGRES RIVER DRAINAGE BASIN
Curves of Discharge Duration
For Period of Twenty Five Years
1890 - 1914 Inclusive
Note - Full lines show number of months that discharge has been above a given quantity
Dotted lines show the mean of the total period
Discharge in Thousand Cubic Feet per Second
Gatun 25 Yrs - 1890-1914
Bohio - 20 Yrs - 1890-1909
Gamboa - 23 Yrs. 1890-1912
Alhajuela 25 Yrs. 1890-1914

Fig. 32.

The river year 1909-1910 was the year of maximum run-off at all stations.

Figs. 26 to 29, inclusive, show the interrelation of these periods of discharge.

Table 43 shows the run-off past Gatun, arranged in periods of maximum flow.

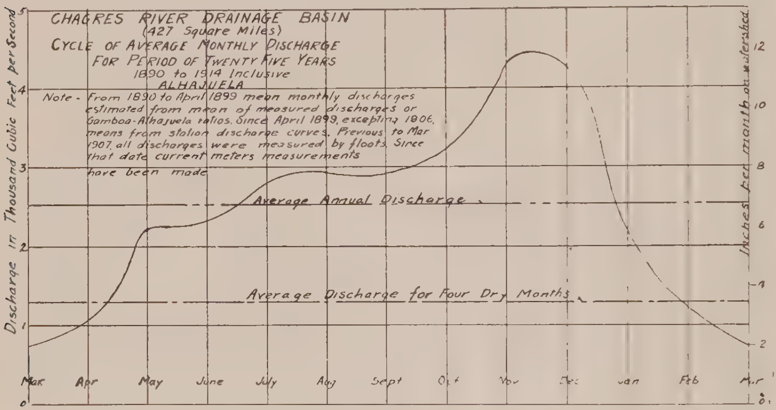


Fig. 33.

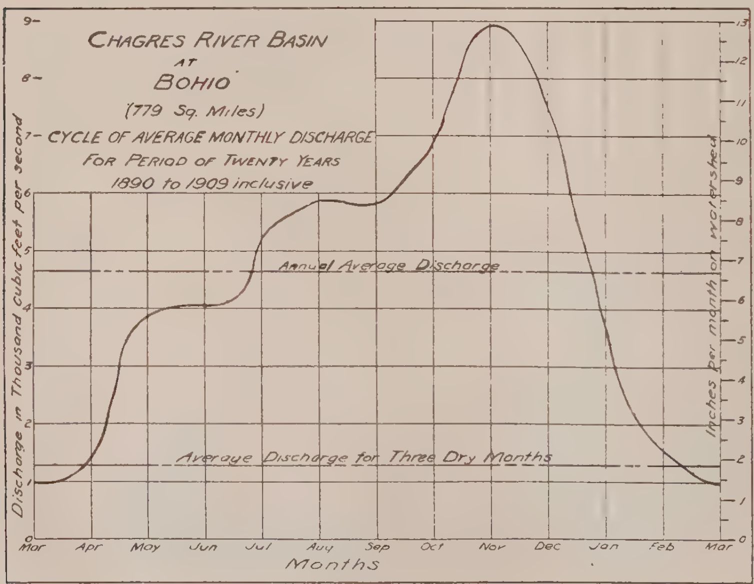


Fig. 34.

Table 44 shows the run-off past Gatun arranged in periods of minimum flow.

The conditions of discharge-duration of the several months placed in order of dryness, together with the mean discharge diagram for the period used for Alhajuela and Gatun are shown on Figs. 30 and 31.

Figure 32 shows the Chagres River drainage basin curves of discharge for a period of 25 years.

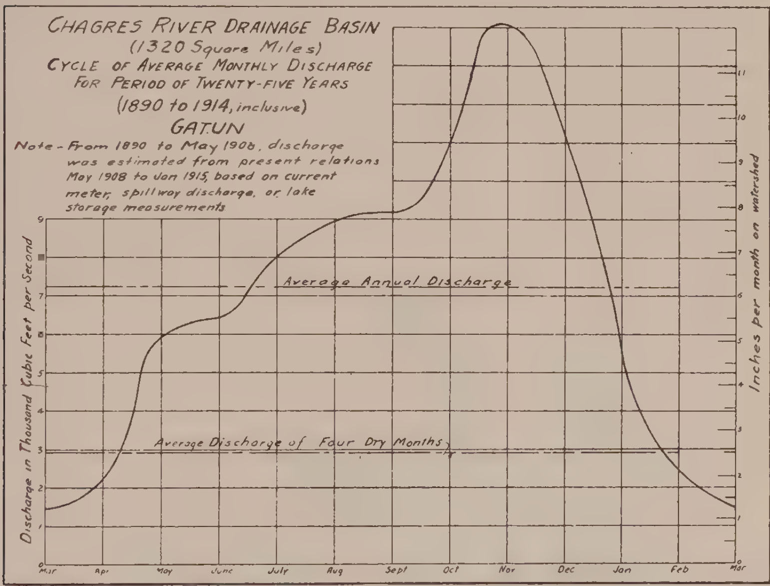


Fig. 35.

The probable quantity of water available for power is shown on the average hydrograph for years of record, Figs. 33, 34 and 35.

Absolute maximum conditions of record at Alhajuela, Bohio, and Gatun are to be found in Table 45.

Figure 37 is a diagram of freshet heights and mass curves in Chagres River, November, 1909.

Figure 39 is a diagram of freshet heights and mass curves, Chagres River, December 26, 1909, and January 8, 1910.

Figures 36 and 38 portray two distinct types of freshet discharge. The freshet of November, 1909, was of comparatively

longer duration and of more widely distributed rainfall than that of the succeeding month, although the momentary discharge at all stations was less than that of the December freshet. The

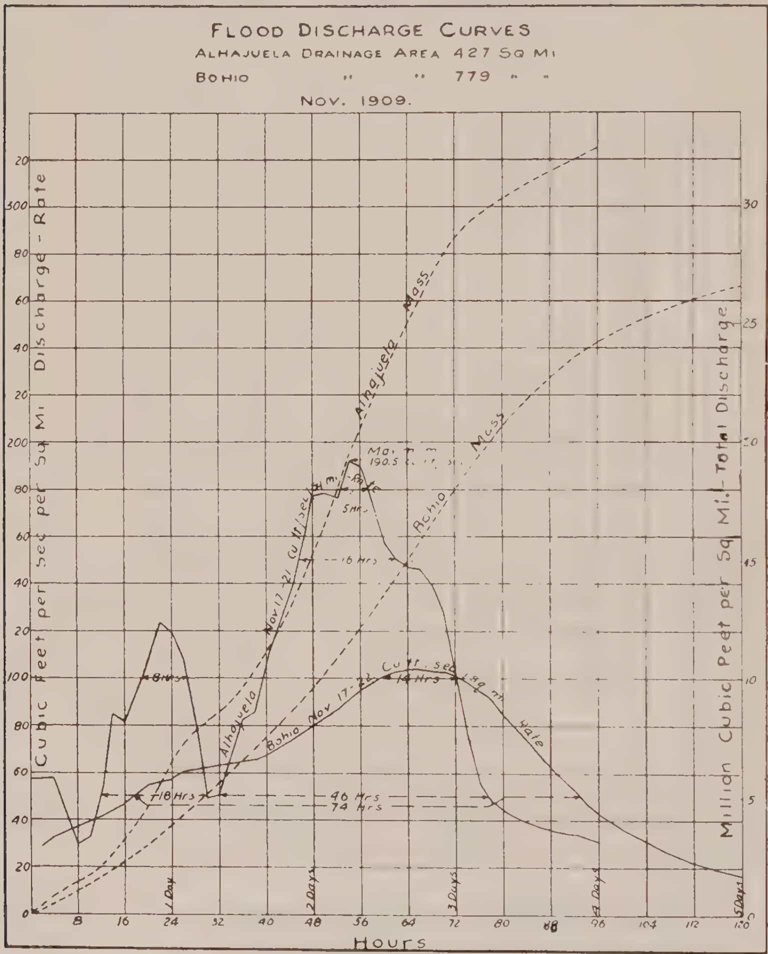


Fig. 36.

discharge of the November flood past Gatun was, however, about fifty per cent greater than that of December.

In connection with the "dry season" freshet of February, 1910, it is to be noted that the total discharge at Gatun was about one fourth of the "wet season" freshet of December, 1909.

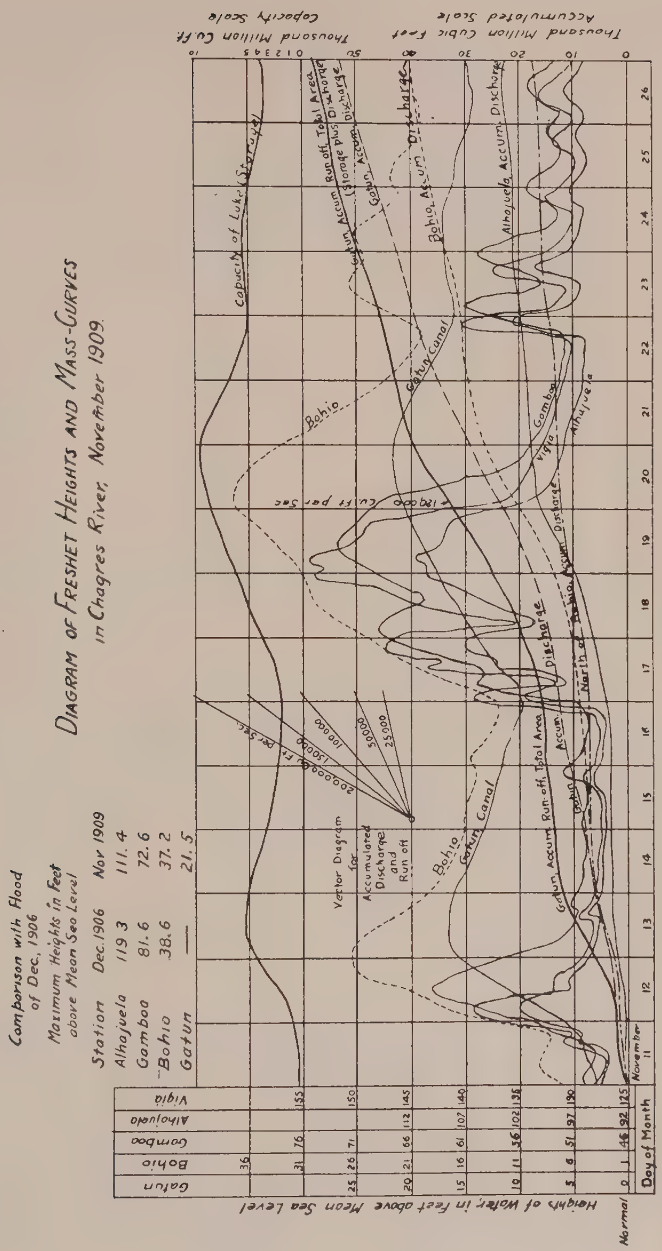


DIAGRAM OF FRESHET HEIGHTS AND MASS-CURVES
in Chagres River, November 1909.
Comparison with flood of Dec., 1906
Maximum Heights in Feet above Mean Sea Level
Station Dec. 1906 Nov 1909
Alhajuela 119.3 111.4
Gamboa 81.6 72.6
Bohio 38.6 37.2
Gatun — 21.5
Vector Diagram for Accumulated Discharge and Run off
Capacity of Lake (Storage)
Thousand Million Cu. ft. Capacity Scale
Thousand Million Cubic Feet Accumulated Scale
Heights of Water in Feet above Mean Sea Level
Day of Month
Gatun
Bohio
Gamboa
Alhajuela
Vigia
Normal
November

Fig. 37.

The surface slope of the Chagres River during flood periods, with time of crest at various places, is shown on Fig. 41, while the comparative flood heights for December 7-18, 1909, are shown on Fig. 42.

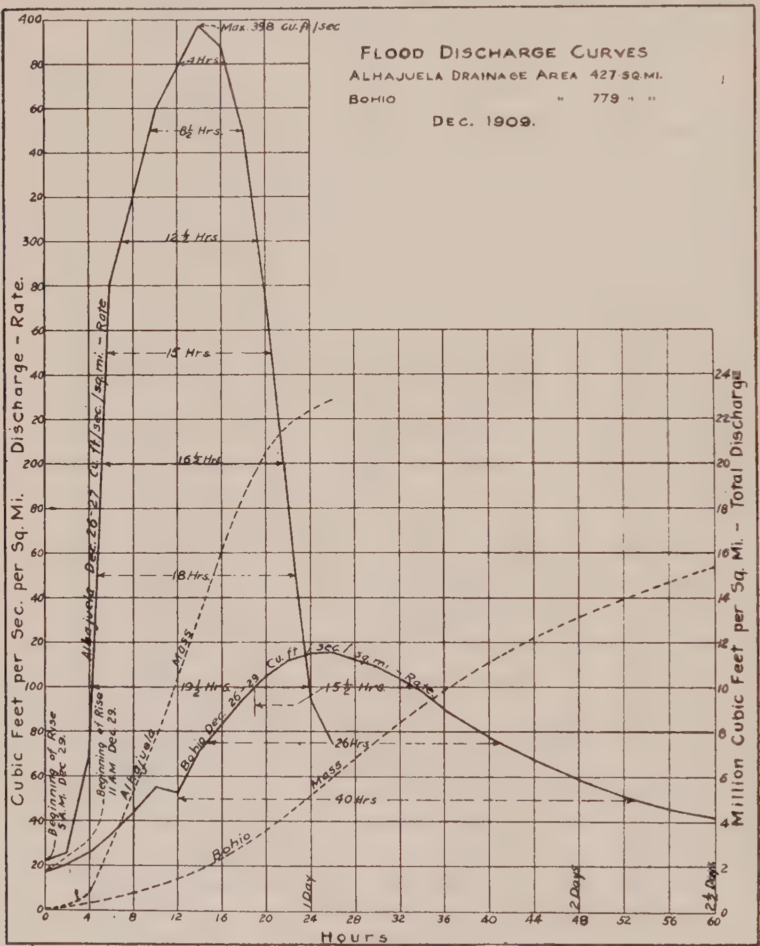


Fig. 38.

The mean maximum velocity of the December flood past Alhajuela was 13.57 feet per second, or more than four times that with which the crest moved down the stream. Further comparison along this line seems to indicate that the crests move

down a stream with about the same velocity, irrespective of gage height, while mean stream velocity is dependent on the gage height.

Figures 43 and 44 show the relation between the rainy and dry season run-off of the streams tributary to Gatun and Miraflores Lakes. Each river is a law unto itself, governed by the geological and topographical conditions of the watershed.

Figures 45 to 50, inclusive, show rainfall, discharge, and retention for years of record, maximum year and minimum year, at Alhajuela and Gatun.

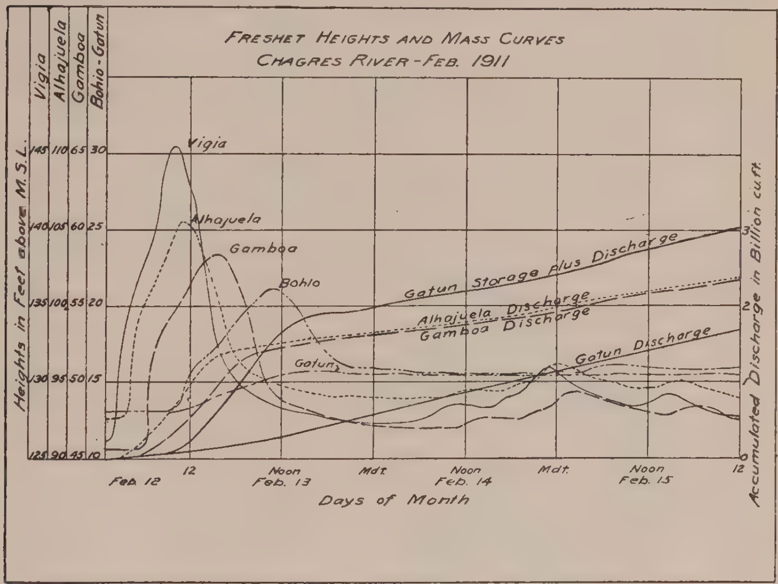


Fig. 40.

Figure 51 shows the profile of the Chagres River and the effect of the back water from the filling of Gatun Lake.

Figure 52 shows cross-section of the Chagres River at Gamboa gaging station, with changes due to excavation for gravel above the gaging station.

The change in the percentage of rise at Vigia to that at Gamboa due to back water effect caused by the filling of Gatun Lake is shown in Figure 53.

The minimum discharge of the various streams during the dry season of 1912 is given in Table 46.

Table 47 gives the discharge at Gatun and Gamboa for dry

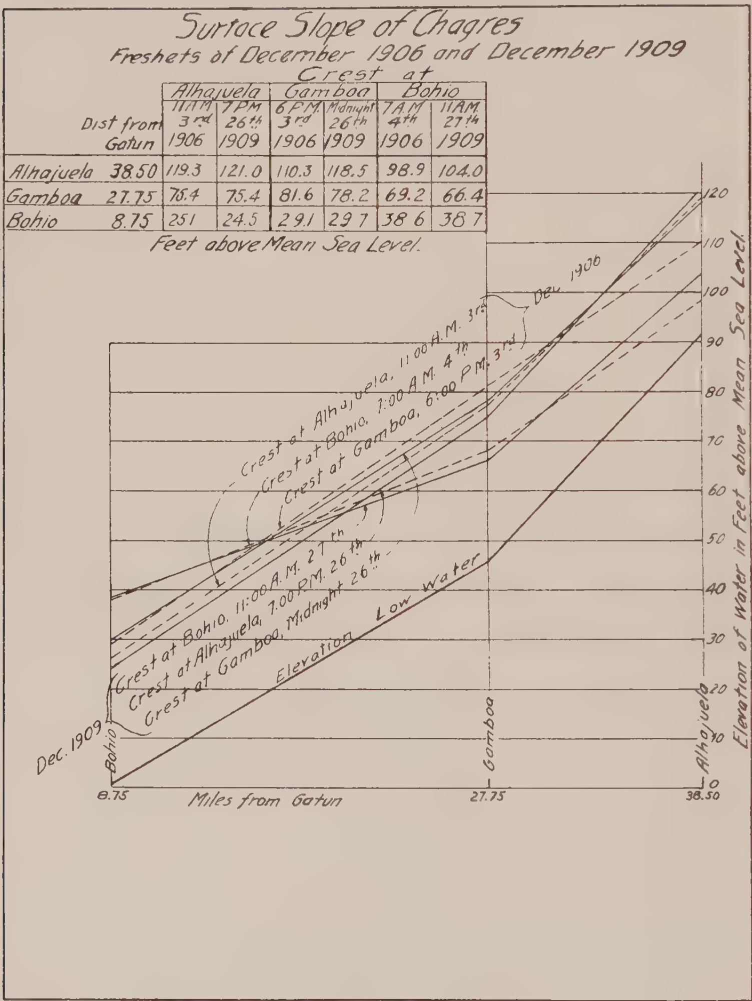


Fig. 41.

and wet seasons and calendar years of maximum and minimum flow; while Table 48 gives the same data for river years, and Table 49 gives Gatun Lake water supply for 1912.

Tables 50 and 51 give the monthly discharge of the Chagres River at Alhajuela for 1913 and 1914 (drainage area 427 square miles), and for Gatun Lake (drainage area 1320 square miles).

TABLE 46.

TABLE GIVING MINIMUM DISCHARGE OF VARIOUS STREAMS DURING THE DRY SEASON, 1912.

Stream and Location	Date	Discharge Sec-feet	Remarks
Gatun Spillway			See special table
Chagres River:			
Gamboa	Apr. 20 and 21	250.00	From discharge curve
Alhajuela	do	250.00	do
Upper Chagres, Dos Bocas	May 7	186.00	Gauging
Pequeni, Dos Bocas	April 10	72.60	do
La Puente, Vigia	May 2	1.77	do
Gatuncillo			Dry Apr. 2 to May 16
Chilibre	Apr. 18	.57	Gauging
Chilibrillo	Apr. 15	.49	(Probably lower on 18th to 21st)
Siri River, above Trinidad	Apr. 18	25.00	Gauging
Trinidad Branch above Trinidad	Apr. 12	17.50	do
Gatun River, at Quebrancha Culverts	May 9	30.10	Drainage above railroad embankment
Cano River, near Zone boundary	Apr 30	8.67	Gauging
Agua Salud, at Panama Railroad	May 9	1.36	do
Frijolito, at Panama Railroad	May 9	1.61	do
Frijoles Grande, at Panama Railroad	May 9	.02	Estimated
Frijoles, at Panama Railroad	May 9	.08	do
Obispo diversion, Gamboa			Dry Feb. 27 to June 22
Mandingo, near Bas Obispo	Apr. 2	.18	
Pedro Miguel	Apr. 6	.20	Gauging
Caimitillo, at culvert			Dry Feb. 12 to Apr. 30
Camaron, at culvert	Apr. 8	.11	Gauging
Cocoli, above reservoir	Apr. 8	.16	do
Rio Grande:			
Bridge No. 57, Panama Railroad	Apr. 9	.24	do
Above reservoir	Apr. 9	.20	do

Table 52 gives the discharge of the rivers tributary to Miraflores Lake for 1911 and 1912, with their respective drainage areas.

The filling of Gatun Lake is shown from April, 1910, to December, 1914, by hydrographs on Figs. 54 to 58, inclusive, while the filling of Miraflores Lake is likewise shown from October, 1913, to December, 1914, on Figs. 59 and 60.

Figs. 61 to 64, inclusive, relative to the study on the filling of Gatun Lake from May to December, 1913.

Figs. 66 and 67 accompany investigation of current below west lower operating gates, Miraflores Lake.

TABLE 49.

Gatun Lake water supply, 1912.

(Values in second-feet. Watershed area, 1,320 square miles.)

Month.	Chagres at Gamboa.	Siri River.	Trinidad River.	Gatun River.	Cano River.	Mandingo River.	Agua Salud.	Frijolito River.	Frijoles Grande.	Frijol River.
January....	801	182	118	142	62	4.6	15	11.5	0.9	12
February...	542	96	70	100	35	1.4	8	7	.3	5.5
March......	366	57	44	62	16	1	5	5	.3	2
April......	372	55.5	30.9	37.2	9.1	.2	2.3	3	.2	.8
May........	1,777	122	59	128	41	2	5.4	4.3	1.1	3.2
June..	2,161	336	108	216	74	10	16.3	12.3	2	18.4
July.......	3,131	269	106	286	94	19	32	19	(1)	29
August.....	3,190	640	340	400	225	22	37	16	(1)	36
September..	3,594	788	244	393	255	50	51	28	(1)	56
October....	4,249	867	595	650	380	75	66	38	(1)	76
November...	6,934	985	675	950	500	75	104	100	(1)	134
December...	3,509	525	380	533	250	20	38	20	(1)	31

(1) Gagings discontinued.

The hydrology of Gatun Lake, Miraflores Lake and the Chagres River for year 1914 is shown in Tables 53 to 55, inclusive.

The hydrographic condition obtaining on all streams tributary to Gatun Lake and Miraflores Lake during the period July, 1911, to August, 1912, is of special interest, chiefly because, during that period, the minimum dry season and total flow for twelve consecutive months, for years of record (January 1, 1890, to December 31, 1914), have occurred. The previous minimum dry-season flow occurred during the calendar year 1908. The total flow for calendar year 1911 was the minimum flow for calendar years of record, except 1905.

At Alhajuela the minimum elevation of the Chagres River occurred on April 20, 1912, when the water-stage register recorded an elevation of 91.0 feet, with a discharge of 250 cu. ft. per second.

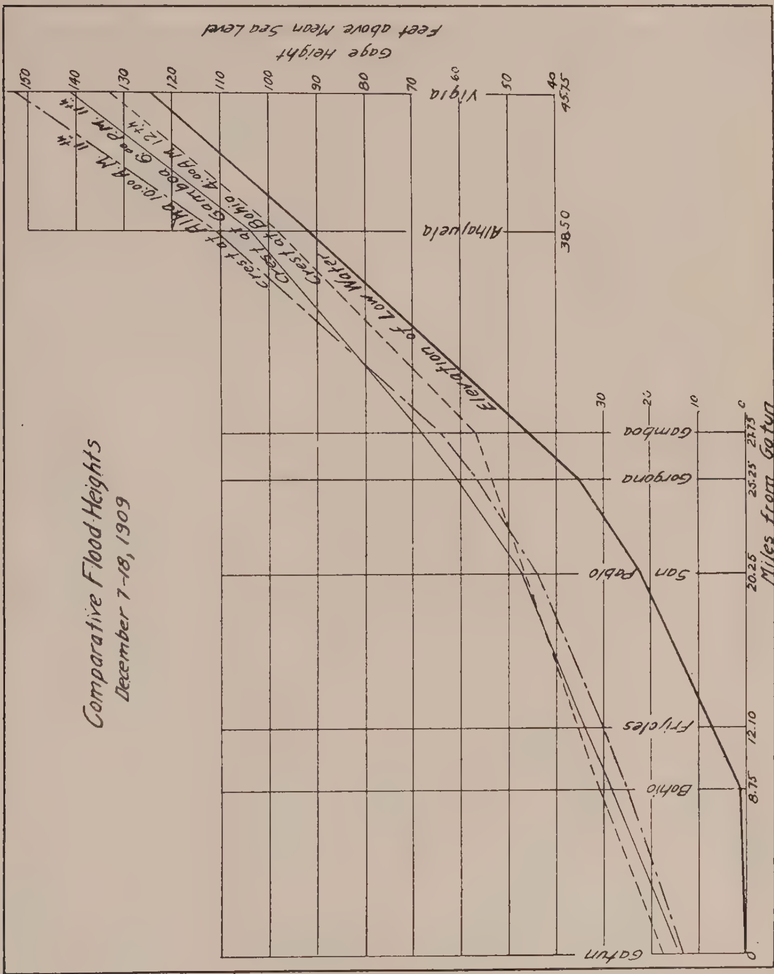


Fig. 42.

The minimum elevation at Gamboa occurred on April 7-8, 1912, when the water-stage register recorded an elevation of 43.5 feet, but the minimum discharge was on April 20th with an

elevation of 43.6, giving a discharge of 250 cu. ft. per second. Changes in the cross section at Gamboa at this time, on account of excavation work, were very rapid. The previous low-water

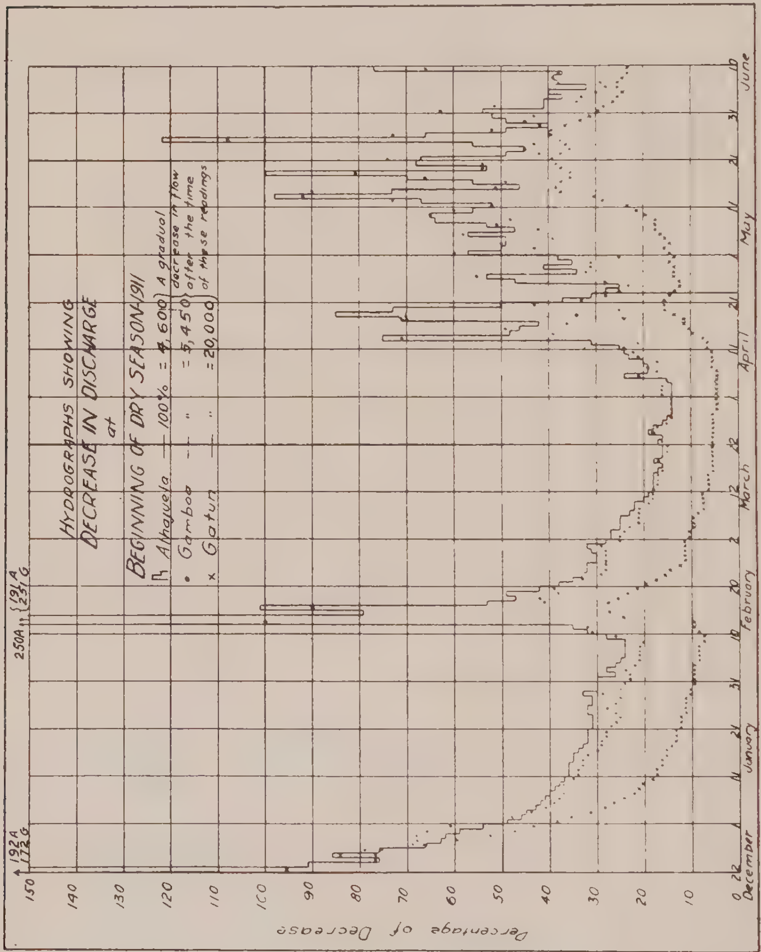


Fig. 43.

records were 91.86 for Alhajuela on April 26, 1905, and 44.40 for Gamboa on April 4, 1911.

Prior to the formation of Gatun Lake, the Alhajuela discharge was about one third of that at Gatun, which is comparable

with that of the two drainage areas, whereas, during the dry season, about one-half of the total Gatun flow passed Alhajuela. Since the filling of the lake, indications point to a modification of these ratios.

The average run-off for a period of 25 years for the entire watershed has been about 62 percent of the rainfall, and the average annual yield per square mile for the Chagres river basin

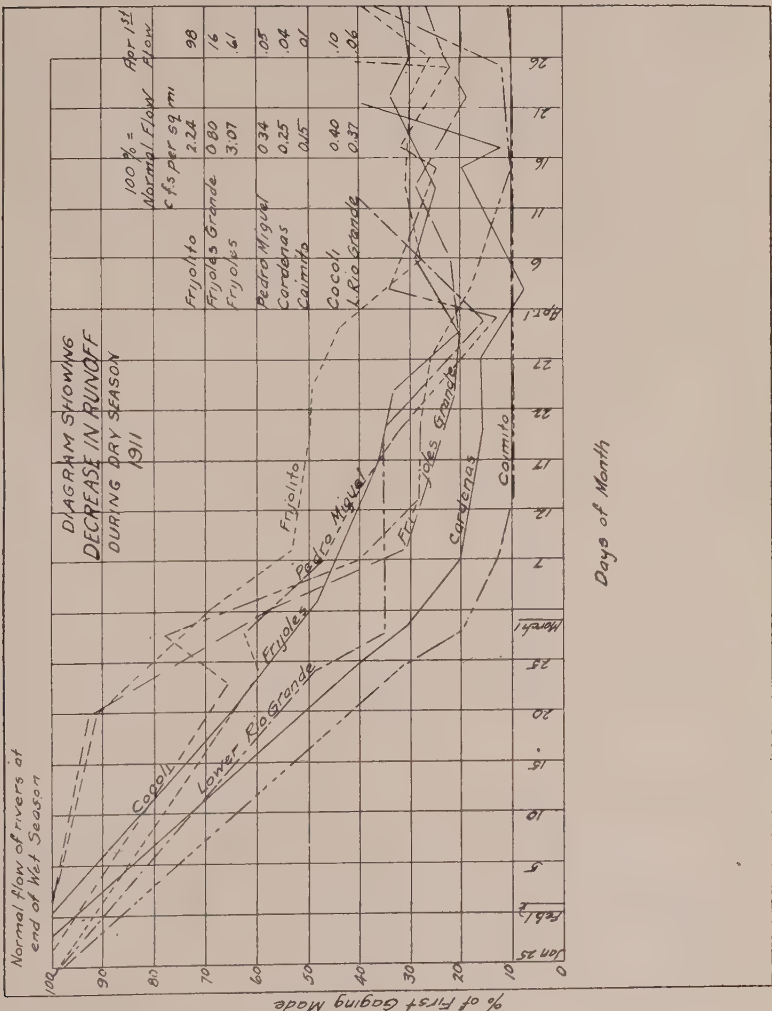


Fig. 44.

above Alhajuela has been 5.91 cu. ft. per second, and for the entire basin 5.47 cu. ft. per second.

The rainfall over the area above Alhajuela has averaged 10 per cent greater than that for the entire drainage basin.

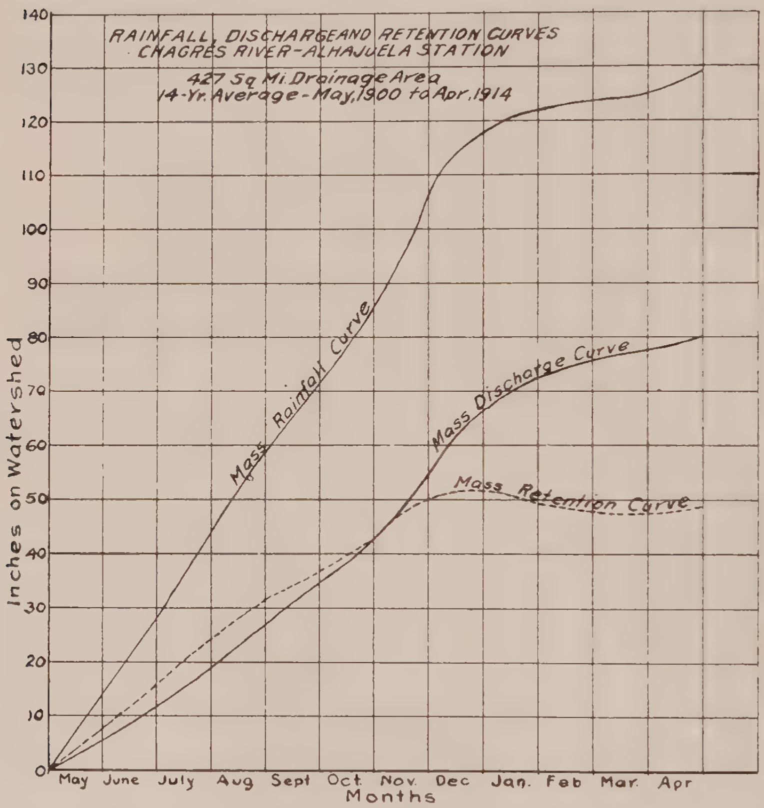
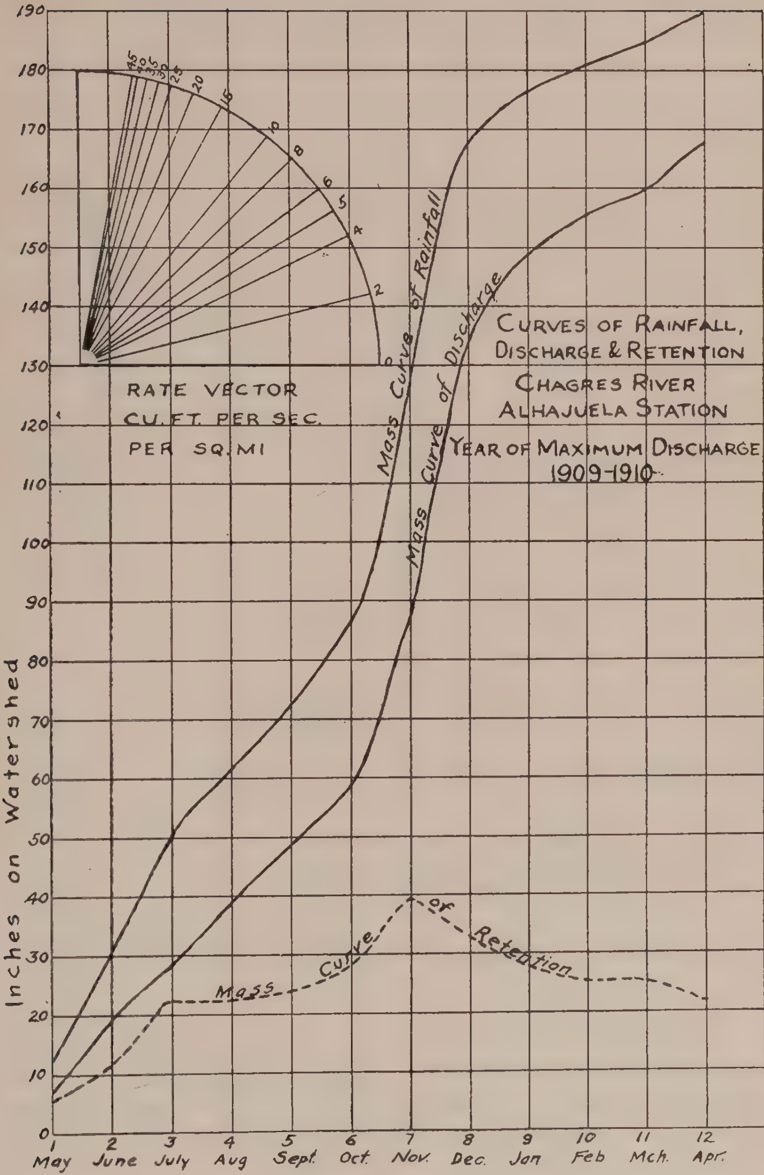


Fig. 45.

Gatun Lake.

Gatun Lake impounds the waters of a basin comprising 1320 square miles. When the surface of the water is 87 feet above sea level, the lake will have an area of about 167.4 square miles and contain about 192.24 billion cubic feet of water. The ratio of water to land surface is 14.5 per cent.

The average rainfall over the whole lake watershed is approximately 120 inches. The average yearly run-off is about 62



CURVES OF RAINFALL, DISCHARGE & RETENTION
CHAGRES RIVER
ALHAJUELA STATION
YEAR OF MAXIMUM DISCHARGE
1909-1910
RATE VECTOR
CU. FT. PER SEC.
PER SQ. MI
Mass Curve of Rainfall
Mass Curve of Discharge
Mass Curve of Retention
Inches on Watershed
1 May
2 June
3 July
4 Aug
5 Sept.
6 Oct.
7 Nov.
8 Dec.
9 Jan
10 Feb
11 Mch.
12 Apr.

Fig. 46.

percent of the rainfall, equivalent to about 235 billion cubic feet of water or about 75 inches over the watershed.

The yearly evaporation over the lake area is about 60 inches. There is no evidence of loss of water from the lake through seepage.

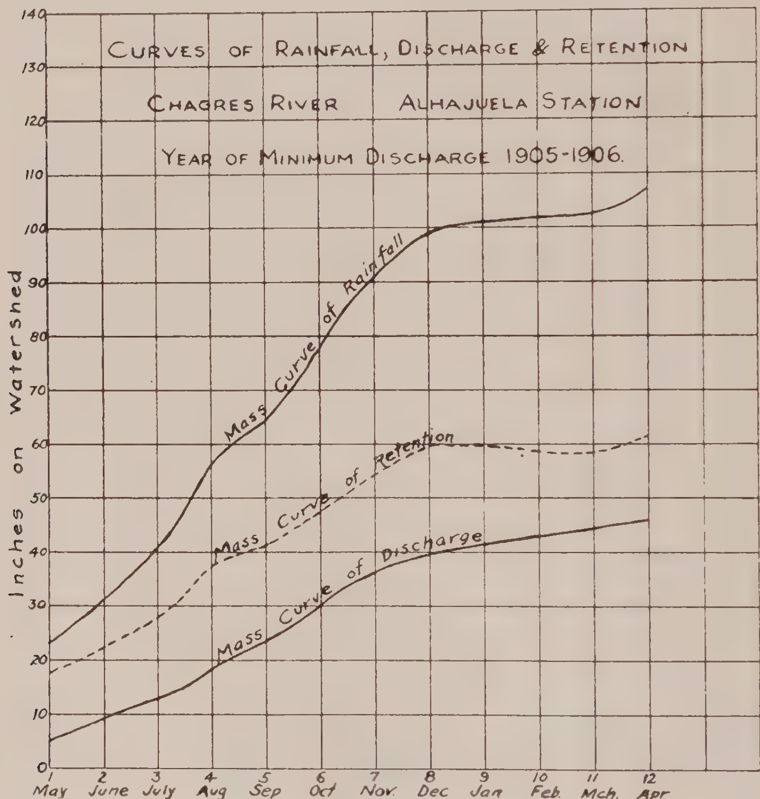


Fig. 47.

The minimum run-off of water in the basin during the past 25 years as measured at Gatun was about 146 billion cubic feet during the year 1905. The maximum run-off, about 360 billion cubic feet, occurred in 1910, a quantity nearly sufficient to fill the lake twice.

During the eight or nine wet months of the year the lake will be kept constantly full by the prevailing rainfall, and con-

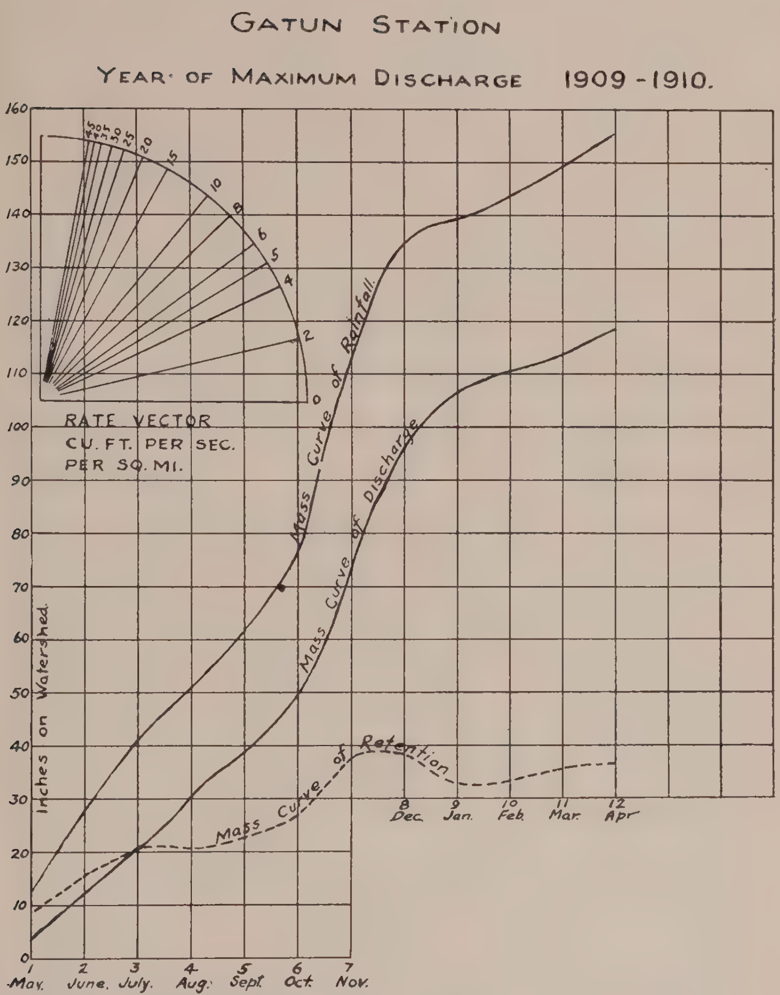

GATUN STATION
YEAR OF MAXIMUM DISCHARGE 1909-1910.
RATE VECTOR
CU. FT. PER SEC.
PER SQ. MI.
Mass Curve of Rainfall.
Mass Curve of Discharge
Mass Curve of Retention
Inches on Watershed.
1 May. 2 June. 3 July. 4 Aug. 5 Sept. 6 Oct. 7 Nov.
8 Dec. 9 Jan. 10 Feb. 11 Mar. 12 Apr

Fig. 48.

sequently a surplus will have to be stored for only three or four months of the dry season. The water surface of the lake will be maintained during the rainy season at 87 feet above mean sea level, making the minimum channel depth in the Canal 47 feet.

Based on the minimum dry-season flow (1911-1912), with lake elevation at 87 feet December 1st, and allowing for power

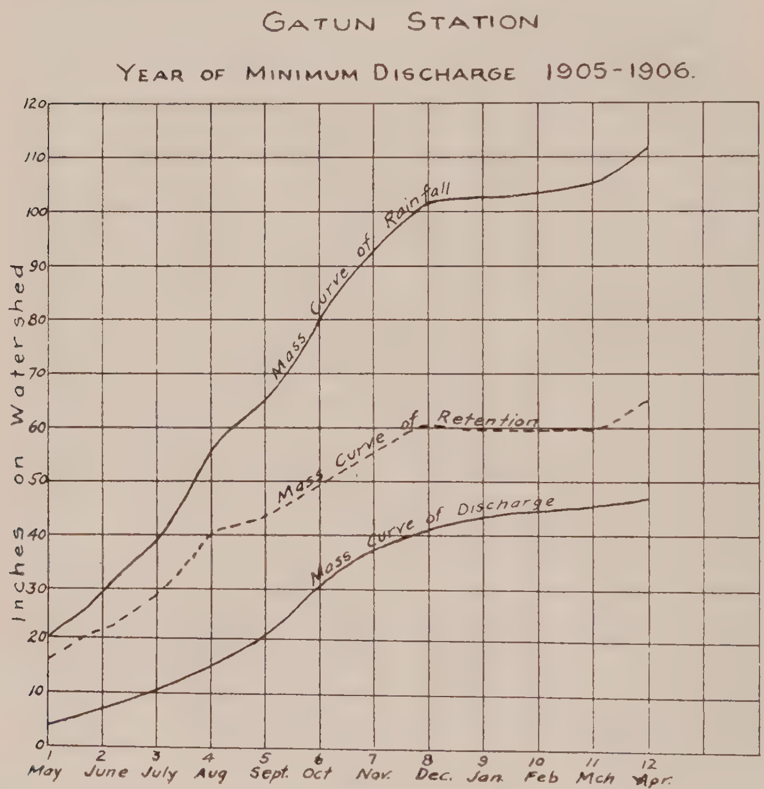


Fig. 49.

consumption, leakage, evaporation and other losses, the water supply would be sufficient to allow an average of 27 lockages per day for the period from December 1st to May 1st without lowering the lake surface below elevation plus 82 feet. In case cross-filling in the lock chambers were employed, the average number of lockages could be increased 12 percent. Thus it will be seen

that during the dryest dry season in 25 years the water supply in Gatun Lake was sufficient to allow the passage of about 30 vessels daily, more than twice the average number that pass through the Suez Canal.

Rates of Consumption.*

One complete lockage per 24 hours equals		54.6	c.f.s.
Power, light, etc.	"	275.0	"
Leakage at gates	"	275.0	"
Other losses	"	85.0	"

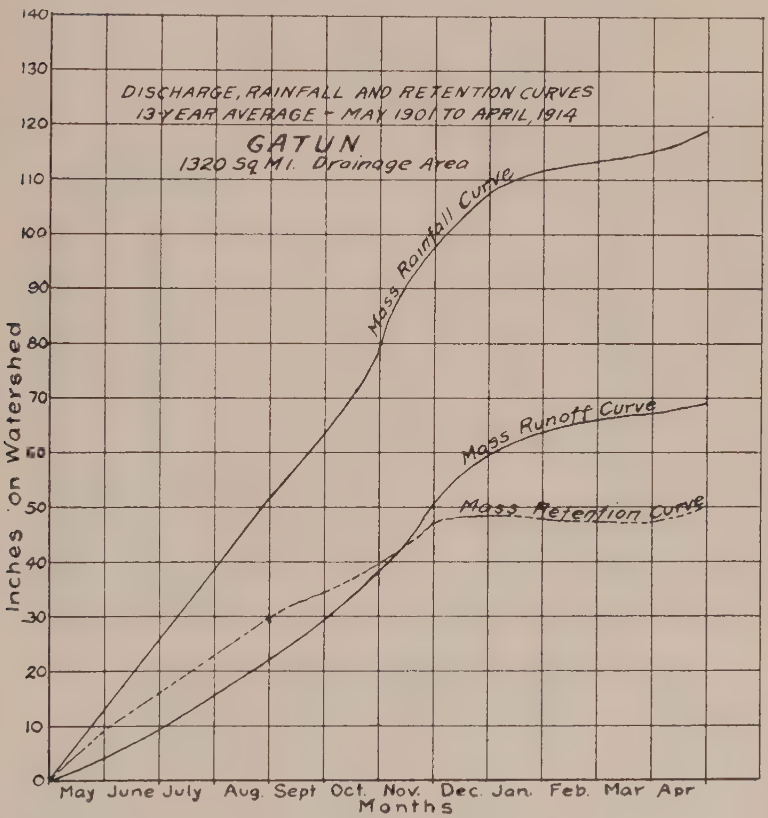


Fig. 50.

* Editor's Note:—The consumption stated per lockage is for the 1000-ft. lock. For the 550-ft. lock it is about 36.4 c.f.s. The leakage at the gates, valves, etc., estimated at 275.0 c.f.s., measured actually 14.57 c.f.s. in the autumn of 1914.

Miraflores Lake.

Miraflores Lake is formed by impounding the waters of the lower Rio Grande, Pedro Miguel, Caimitillo, Cameron and Cocoli

TABLE 53.

THE PANAMA CANAL

Department of Operation and Maintenance

Division of Meteorology and Hydrography

--oOo--

Hydrology of Gatun Lake Watershed
(Drainage area - 1,320 sq. mi.)
Year 1914

Gatun Lake	Elev.	Date
Yearly mean	85.26	
Maximum	87.07	Dec.24-27
Minimum	84.13	January 6

	Quantities Million cubic feet	Second feet
Gatun spillway, waste	139,285.	4416.7
Gatun spillway, leakage	574.	18.2
Gatun locks, lockage and tests	2,501.	79.3
Gatun locks, leakage	151.	4.8
Gatun hydroelectric plant	3,604.	114.3
Pedro Miguel locks, lockage and tests	2,681.	85.0
Pedro Miguel locks, leakage	104.	3.3
Pumping at Cucaracha slide	265.	8.4
Brazos Brook reservoir	208.	6.6
Pumping at Pedro Miguel into Miraflores Lake . .	189.	6.0
(a) Total outflow	149,562.	4742.6
(b) STORAGE (plus, increase; minus, decrease). .	12,154.	385.4
(c) Net yield (a plus b)	161,716.	5128.0
(d) Evaporation on lake (62.89")	23,970.	760.1
(e) Total yield (c plus d)	185,686.	5888.1
(f) Rainfall on lake (92.08")	35,040.	1111.1
(g) Yield from land area (e minus f)	150,646.	4777.0

	Mean area. Sq. mi.	Rainfall. Inches.	Runoff. Inches.	Percentage runoff.
Lake surface	164.	92.08	92.08	100.00
Land area	1156.	101.76	56.09	55.19
Total watershed	1320.	100.54	60.55	60.24

rivers. It has a drainage area of 38.5 square miles. The area of the lake surface at elevation plus 55 feet is 1.65 square miles, with a capacity of 908 million cubic feet.

The tributary streams all lie on the leeward side of the Continental Divide in a region of comparatively light rainfall. Dur-

ing the dry months the evaporation from the lake surface exceeds the inflow.

The Miraflores Lake watershed run-off for the dry season 1914 amounted to nine million cubic feet, including a negative

TABLE 54.

THE PANAMA CANAL

Department of Operation and Maintenance

Division of Meteorology and Hydrography
--oOo--

Hydrology of Miraflores Lake Watershed.
(Drainage area - 38.5 sq. mi.)
Year 1914

Miraflores Lake	Elev.	Date
Yearly mean	52.21	
Maximum	54.40	Nov. 16
Minimum	42.49	April 13

	Quantities Million cubic feet	Second feet
Miraflores spillway, waste	1710.8	54.22
Miraflores spillway, leakage	544.7	17.27
Miraflores locks, lockage and tests	2167.2	68.72
Miraflores locks, leakage	135.7	4.31
Miraflores filter plant	259.9	8.24
Miraflores power plant	293.8	9.31
Miraflores west emergency dam pit seepage . . .		
(a) Total outflow	5112.1	162.10
(#) Total inflow from Gatun Lake	-3241.6	-102.79
(b) Storage (plus, increase; minus, decrease) .	153.3	4.86
(c) Net yield (a plus-or-minus # plus b) . . .	2025.8	64.23
(d) Evaporation on lake (57.67")	198.2	6.28
(e) Total yield (c plus d)	2227.6	70.64
(f) Rainfall on lake (70.27")	252.1	8.00
(g) Yield from land area (e minus f)	1975.5	62.64

	Mean area. Sq. mi.	Rainfall. Inches.	Runoff. Inches.	Percentage runoff.
Lake surface	1.51	70.27	70.27	100.00
Land area	36.99	69.81	22.81	32.80
Total watershed	38.50	69.80	24.82	35.60

yield of 21.33 million cubic feet during February and March. The evaporation amounted to 81 million cubic feet. Except for water supplied to this lake from Gatun Lake, it would have fallen to an elevation of approximately 16 feet above sea level or 38.7 feet below its normal operating level by April 30th.

Miraflores Lake may always be kept at its operating level by water from Gatun Lake. To fill it completely from Gatun Lake would lower the latter 0.20 of a foot from elevation 85 above sea level.

GATUN LAKE.

Areas and Volumes.

Contour Feet above Mean Sea Level	Area		Volume		Acre Feet
	Square Feet	Square Miles	Cubic Feet	Gallons	
0	11,549,376	0.44	....	....	....
10	384,834,783	13.81	1,981,920,790	14,824,767,500	45,499
20	813,349,126	29.17	7,972,840,340	59,636,845,700	183,031
30	1,425,899,458	51.14	19,169,083,260	143,384,742,800	440,062
40	1,970,738,955	70.69	36,152,275,320	270,419,019,400	829,942
50	2,528,937,595	90.71	58,650,658,080	438,706,922,400	1,346,434
60	3,099,155,666	111.17	86,791,124,380	649,197,610,400	1,992,450
70	3,670,295,420	131.65	120,638,379,810	902,375,081,000	2,769,476
80	4,274,399,597	153.32	160,361,854,900	1,199,506,674,700	3,681,401
85	4,554,874,320	163.38	183,136,226,495	1,369,858,974,200	4,204,228
90	4,835,349,042	173.44	205,910,598,090	1,540,211,273,700	4,727,056

Prediction of Rises.

For predicting the probable height at Gamboa, the ratios between Gamboa and Vigia were employed. For predicting the probable elevation of Gatun Lake, a study of the volume of flow into the lake from past rises was made, noting what portion of the flow passed Alhajuela and Gamboa up to the time of the crest at each station, also the total flow for the twenty-four hour periods. The relation between the flow at Alhajuela, Gamboa, and total flow into the lake for given periods (usually one, two, or three days) indicated what might be expected to occur under similar conditions. This method was found to be more reliable than taking the ratio between actual rises on the lake and at Gamboa and Alhajuela. At the time of predicting elevations for the lake, the influence of the Trinidad River on the situation was always an unknown factor, but as a general rule the error was always on the side of safety.

The rise in Gatun Lake checked the force of the freshet rises at Gamboa. The back-water from Gatun Lake was felt appreciably at this station about September 1, 1912. Until Sep-

tember, the average ratio between Gamboa and Vigia rise, using yearly means, was 0.72, the maximum being 0.84, and the minimum 0.60. This ratio varies with the rise at Vigia and the elevation of the lake. Special formulae and curves were used in prediction work at Gamboa and Gatun since September, 1912.

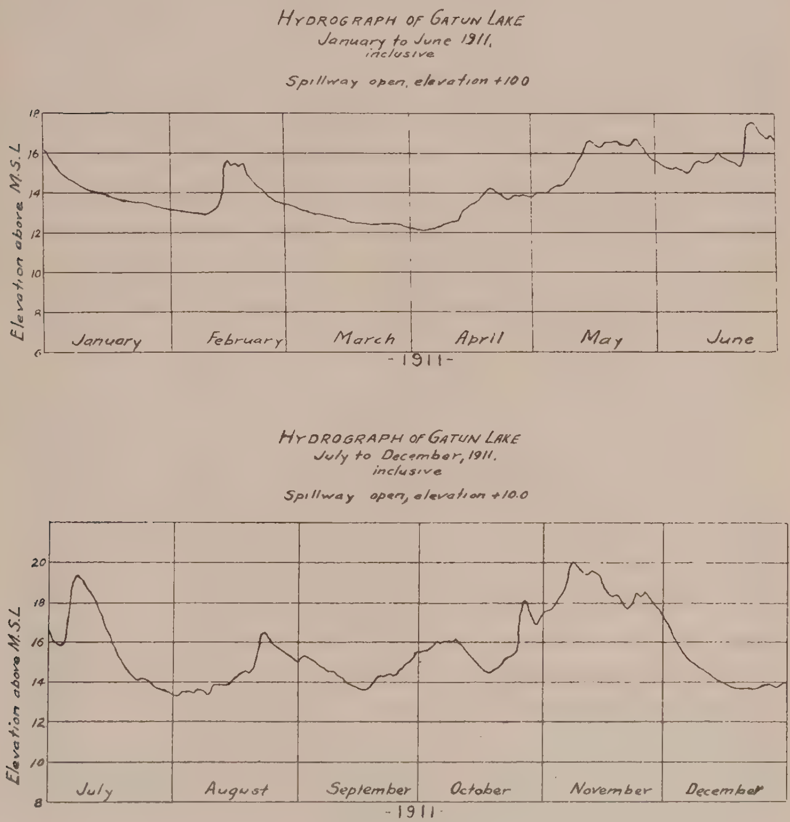


Fig. 54.

Figure 53 shows the profile of water surface for freshets of December, 1909, December, 1910, and November, 1912; also low water, 1909, April, 1912, October, 1914, and the bottom of the river 1909. This diagram shows clearly the effect of the Gatun Lake in checking these floods, also that the river bottom has been

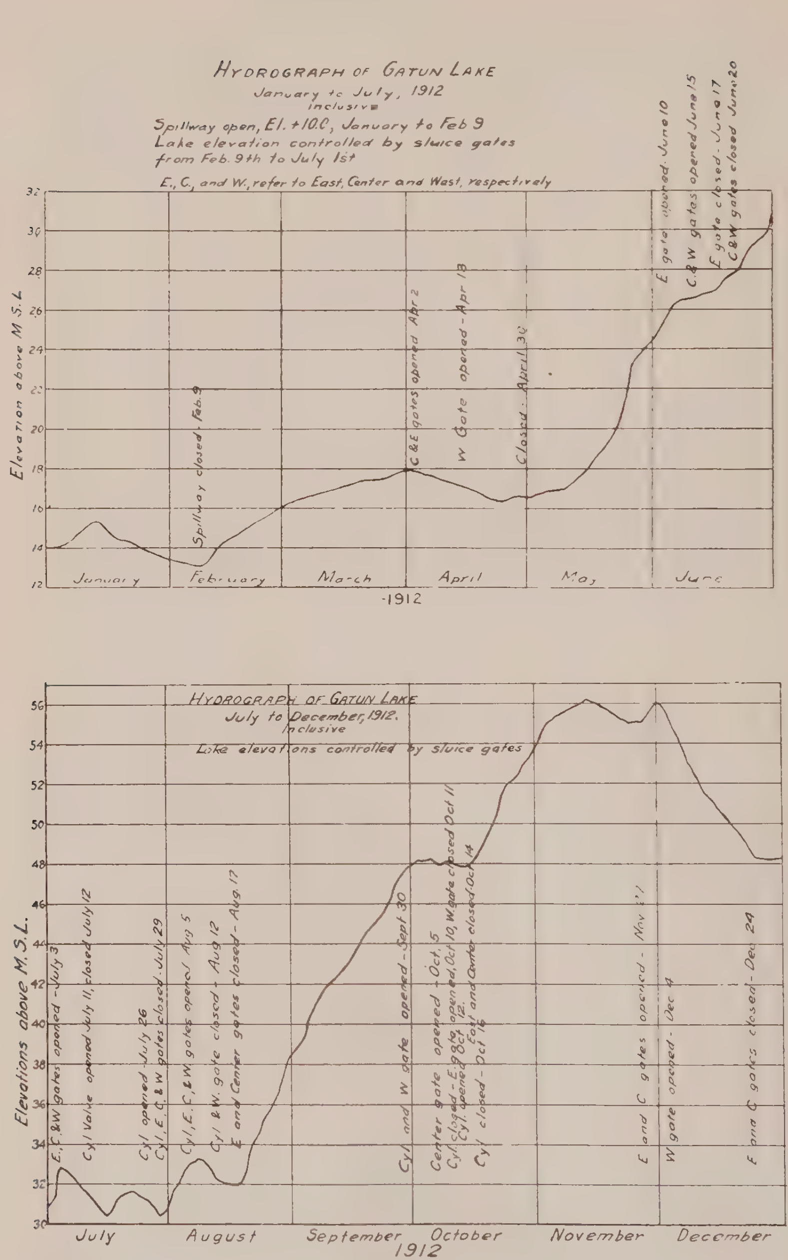

HYDROGRAPH OF GATUN LAKE
January to July, 1912
inclusive
Spillway open, El. +10.0, January to Feb 9
Lake elevation controlled by sluice gates
from Feb. 9th to July 1st
E., C., and W., refer to East, Center and West, respectively
Elevation above M.S.L.
Spillway closed Feb. 9
C&E gates opened Apr 2
W Gate opened - Apr 18
Closed: April 30
E gate opened June 10
C&W gates opened June 15
E gate closed. June 17
C&W gates closed June 20
January
February
March
April
May
June
1912
HYDROGRAPH OF GATUN LAKE
July to December, 1912.
Inclusive
Lake elevations controlled by sluice gates
Elevations above M.S.L.
E., C. & W gates opened - July 3
Cyl Valve opened July 11, closed July 12
Cyl opened July 26
Cyl, E, C, & W gates closed July 29
Cyl, E, C, & W gates opened Aug 5
Cyl & W. gate closed - Aug 12
E and Center gates closed - Aug 17
Cyl and W gate opened - Sept 30
Center gate opened - Oct. 5
East and Center closed Oct 14
Cyl closed - Oct 16
E and C gates opened - Nov 27
W gate opened - Dec 4
E and C gates closed - Dec 24
July
August
September
October
November
December
1912

Fig. 55.

lowered at Gamboa since 1909, due to excavation work and increased velocity due to greater slope.

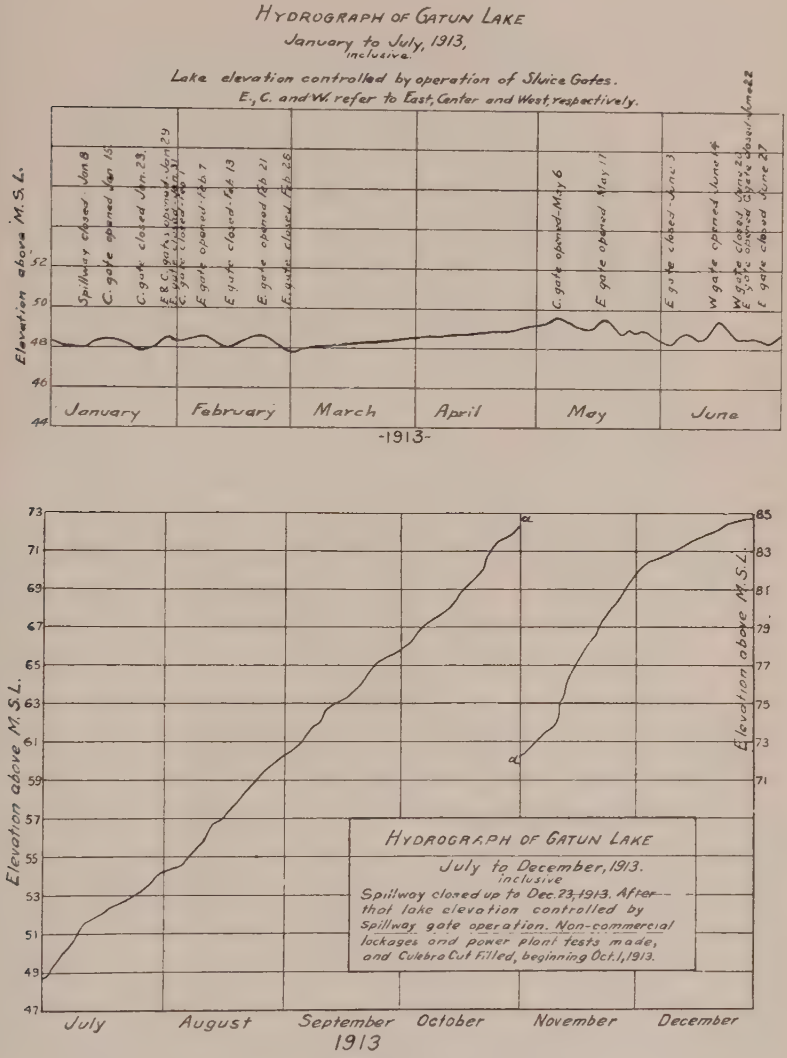
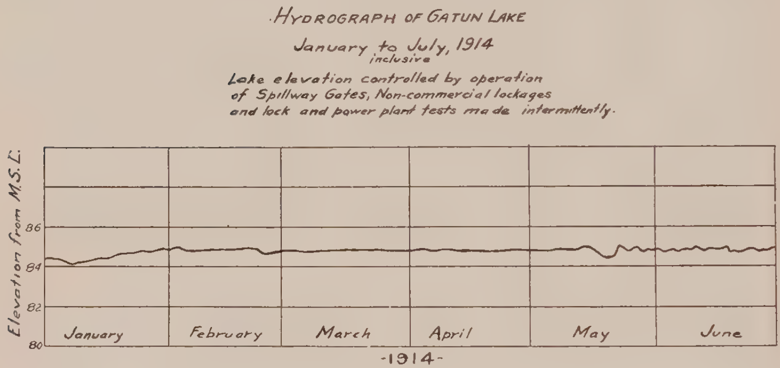


Fig. 56.

The following table shows the yearly average ratio of Gamboa crest, during rises, to the Vigia crest:

Calendar Year	Ratio	Remarks
1908	84.1%	December only; no other records.
1909	84.4%	
1910	75.4%	
1911	71.2%	
1912	60.0%	Lake Ele. from 13.10 to 56.28
1913	12.5%	Lake Ele. from 47.78 to 84.80
1914	1.2%	May and September 10-16 records only. Other rises at Gamboa prevented by spillway operation.



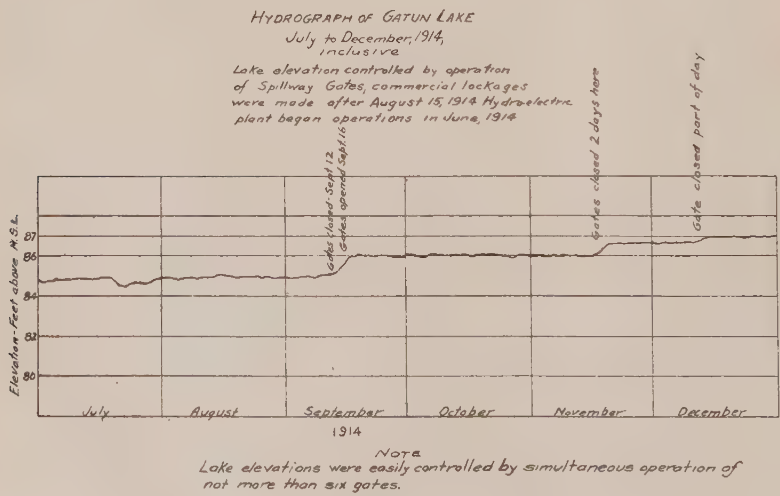


Fig. 57.

TABLE 50.

Monthly discharge - Chagres River

ALHAJUELA
1913
(Drainage area, 427 square miles.)

Month	Discharge in second-feet: Maximum	Minimum	Mean	Per square mile	Run-off (depth in inches on watershed)
1913					
January	5,260	1,270	1,795	4.20	4.842
February	2,770	745	1,177	2.76	2.874
March	1,980	535	695	1.63	1.877
April	950	380	501	1.17	1.310
May	26,300	520	2,051	4.80	5.534
June	9,120	1,070	1,995	4.76	5.210
July	13,200	1,020	2,005	4.70	5.419
August	16,680	1,315	2,530	5.92	6.825
September	20,000	1,700	2,802	6.56	7.319
October	15,300	1,685	2,653	6.21	7.159
November	34,000	1,830	6,168	14.44	16.111
December	5,590	1,720	2,328	5.45	6.283
The Year	34,000	380	2,225	5.21	5.897

[redacted]
1913
(Drainage area, 1,320 square miles.)

1 Month	2 Mean elevation (feet above mean sea level)	3 Area for mean elevation Sq. Mi.	4 Spillway discharge. Sec.-feet	5 Storage (+increase; -decrease) Sec.-feet	6 Evaporation from lake surface Sec.-feet	7 Run-off net yield (4 + 5) Sec.-feet	8 Total yield (4+5+6) Sec.-feet
1913							
January	48.22	87.1	2,542	+ 41	417	2,583	3,000
February	48.34	87.3	1,827	- 529	580	1,298	1,878
March	48.25	87.2	17*	+ 661	651	578	1,329
April	48.77	87.8	15*	+ 552	580	567	1,147
May	49.06	88.5	5,630	- 638	355	4,992	5,347
June	48.61	87.7	4,823	+ 289	355	5,112	5,467
July	52.02	94.7	5*	+ 5,364	384	5,369	5,753
August	57.32	105.6	0	+ 6,896	418	6,896	7,314
September	63.40	118.1	0	+ 7,292	521	7,292	7,813
October	69.32	130.4	181**	+ 8,678	490	8,859	9,349
November	77.48	147.7	22***	+15,295	472	15,317	15,789
December	83.66	160.5	109***	+ 4,198	584	4,307	4,891
The Year	57.87	106.88	1,264	+ 4,008	484	5,264	5,756

* Gate leakage.
** Filling Culebra Cut, 176; lockage, 5.
*** From December, total outflow from lake, including lockages, leakage, pumping, etc.

TABLE 51.

Monthly discharge - Chagres River

ALHAJUELA
1914
(Drainage area, 427 square miles.)

Month	Discharge in second-feet: Maximum	Minimum	Mean	Per square mile	Run-off (depth in inches on watershed)
1914					
January	2,255	830	1,306	3.06	3.528
February	1,175	670	824	1.93	2.010
March	640	401	530	1.24	1.430
April	1,730	305	469	1.10	1.227
May	23,680	359	2,049	4.80	5.534
June	20,050	1,082	2,084	4.88	5.445
July	25,600	785	1,399	3.28	3.781
August	21,980	818	2,066	4.84	5.580
September	28,820	1,926	4,334	10.15	11.325
October	31,650	2,690	5,135	12.03	13.869
November	19,500	2,306	3,804	8.91	9.941
December	23,690	2,058	3,213	7.52	8.670
The Year	31,650	305	2,269	5.31	6.028

GATUN LAKE
1914
(Drainage area, 1,320 square miles.)

1 Month	2 Mean elevation (feet above mean sea level)	3 Area for mean elevation Sq. Mi.	4 Spillway discharge. * Sec. feet.	5 Storage (+increase; -decrease) Sec. feet	6 Evaporation from lake surface Sec. feet	7 Run-off net yield (4 + 5) Sec. feet.	8 Total Yield (4+5+6) Sec. feet
January	84.54	162.6	1,026	+ 713	680	1,739	2,419
February	84.86	163.0	930	- 186	987	744	1,731
March	84.82	162.9	148	+ 19	1,062	167	1,229
April	84.82	162.9	169	+ 139	974	308	1,282
May	84.81	162.8	3,353	- 134	743	3,219	3,962
June	84.85	162.9	5,715	+ 69	665	5,784	6,449
July	84.78	162.8	1,898	0	780	1,898	2,678
August	84.93	163.1	4,741	+ 179	664	4,920	5,584
September	85.57	164.8	7,530	+ 2,311	602	9,841	10,443
October	86.01	165.6	14,938	- 187	608	14,752	15,360
November	86.26	166.0	9,925	+ 1,229	621	11,153	11,775
December	86.87	167.0	6,538	+ 472	[redacted]	7,010	7,747
The Year	85.26	163.8	4,743	+ 385	760	5,128	5,888

* Includes leakages, lockages, pumping and power.

TABLE 52.

DISCHARGE TABLE

Rivers tributary to Miraflores Lake.

Date 1911	(Area=9.97 sq. mi.) Pedro Miguel C. F. S. Mean Discharge	(Area=13.70 sq. mi.) Cocoli C. F. S. Mean Discharge	(Area=10.44 sq. mi.) Caimito River C. F. S. Mean Discharge	(Area=4.37 sq. mi.) Lower Rio Grande C. F. S. Mean Discharge	Date 1912	(Area=9.97 sq. mi.) Pedro Miguel C. F. S. Mean Discharge	(Area=13.70 sq. mi.) Cocoli C. F. S. Mean Discharge	(Area=10.44 sq. mi.) Caimito River C. F. S. Mean Discharge	(Area=4.37 sq. mi.) Lower Rio Grande C. F. S. Mean Discharge
Jan.	3.50	4.00	3.00	3.34	Jan.	3.34	4.70	2.31	3.18
Feb.	2.25	3.50	.77	2.14	Feb.	.89	1.60	.54	.65
Mar.	1.00	1.50	.25	.96	Mar.	.32	.45	.50	.30
Apr.	1.10	.60	.15	1.05	Apr.	.25	.44	.43	.24
May	12.40	11.95	8.40	11.84	May	2.69	3.00	3.60	2.56
June	9.40	9.05	4.60	8.96	June	6.53	6.30	5.75	6.23
July	16.80	16.20	13.40	16.05	July	22.20	21.40	25.80	21.20
Aug.	17.10	16.55	9.10	16.31	Aug.	28.90	27.80	40.00	27.60
Sep.	15.20	14.65	13.00	14.51	Sep.	34.90	33.60	43.60	33.30
Oct.	52.90	51.00	55.50	50.45	Oct.	43.20	41.60	42.20	41.20
Nov.	64.30	62.00	88.50	61.40	Nov.	41.70	57.20	74.60	39.70
Dec.	13.30	12.80	5.20	12.70	Dec.	16.50	15.90	17.00	15.80
Monthly Mean	17.44	16.98	16.82	16.64	Monthly Mean	16.78	17.83	21.36	16.01

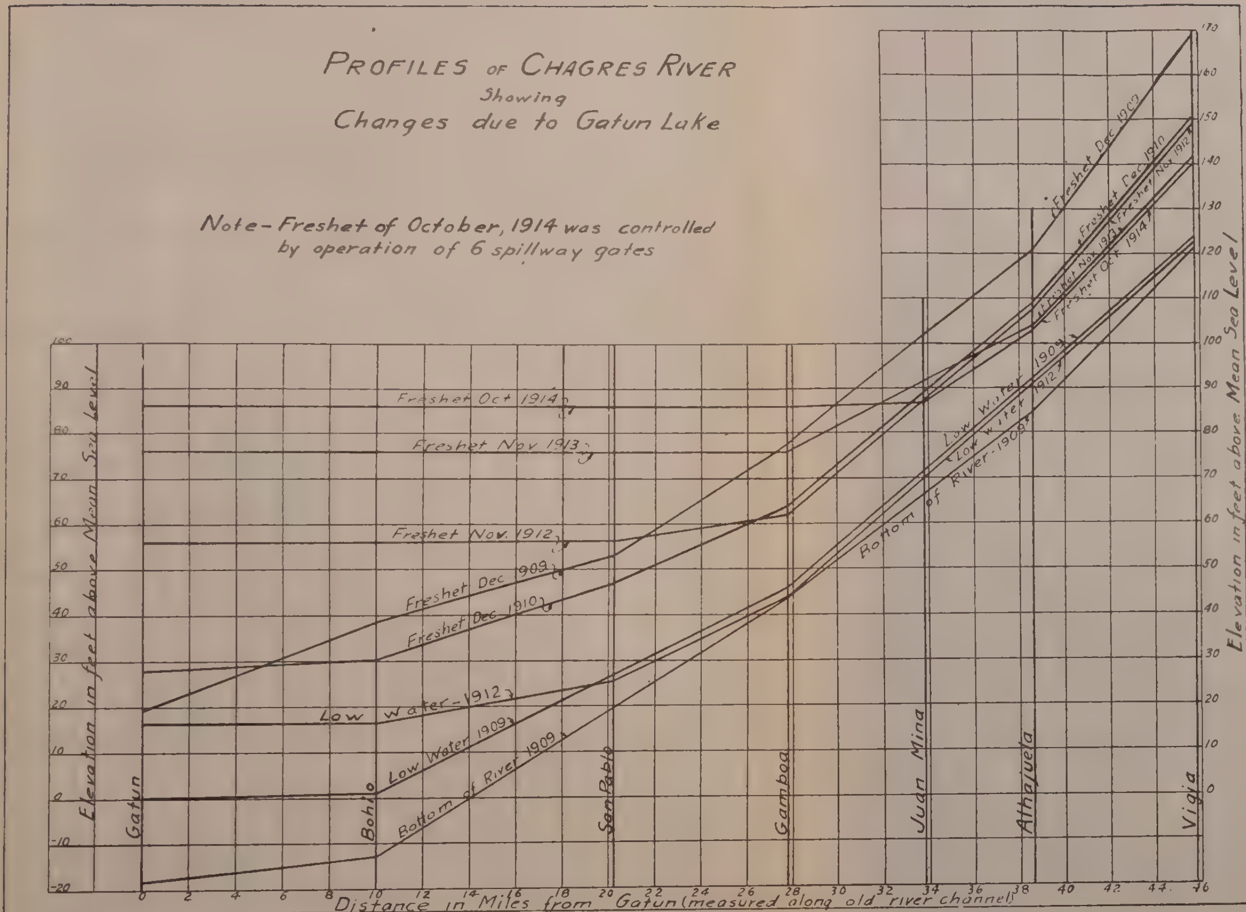

PROFILES OF CHAGRES RIVER
Showing
Changes due to Gatun Lake
Note-Freshet of October, 1914 was controlled
by operation of 6 spillway gates
Freshet Oct 1914
Freshet Nov 1913
Freshet Nov. 1912
Freshet Dec 1909
Freshet Dec 1910
Low water-1912
Low Water 1909
Bottom of River 1909
Gatun
Bohio
San Pablo
Gamboa
Juan Mina
Alhajuela
Vigia
Elevation in feet above Mean Sea Level
Distance in Miles from Gatun (measured along old river channel)

Fig. 51.

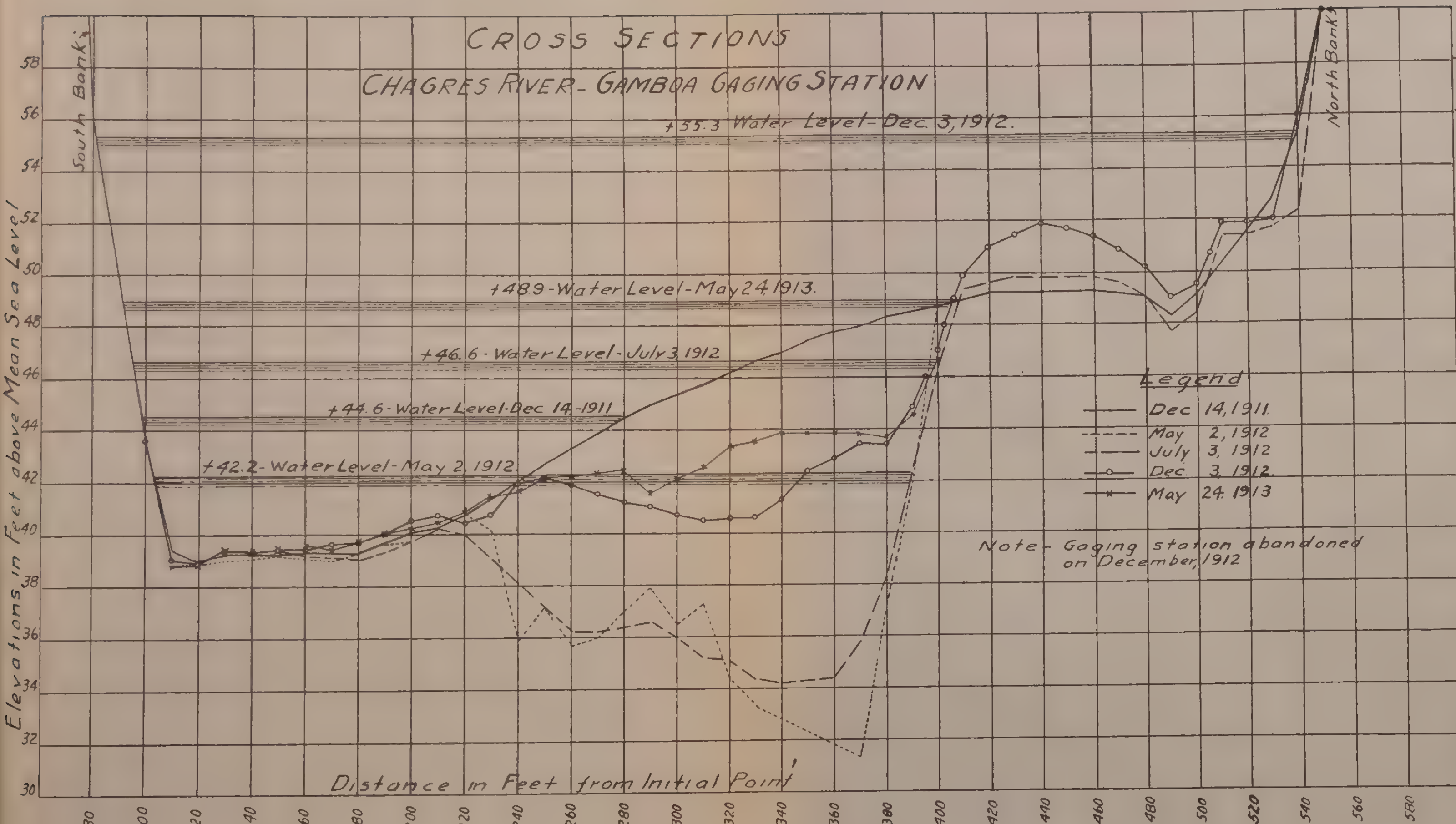
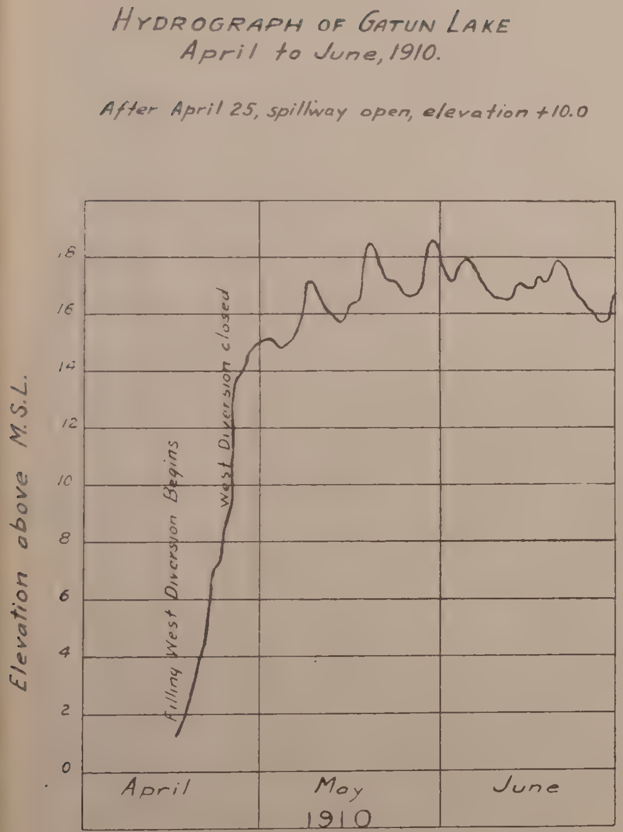
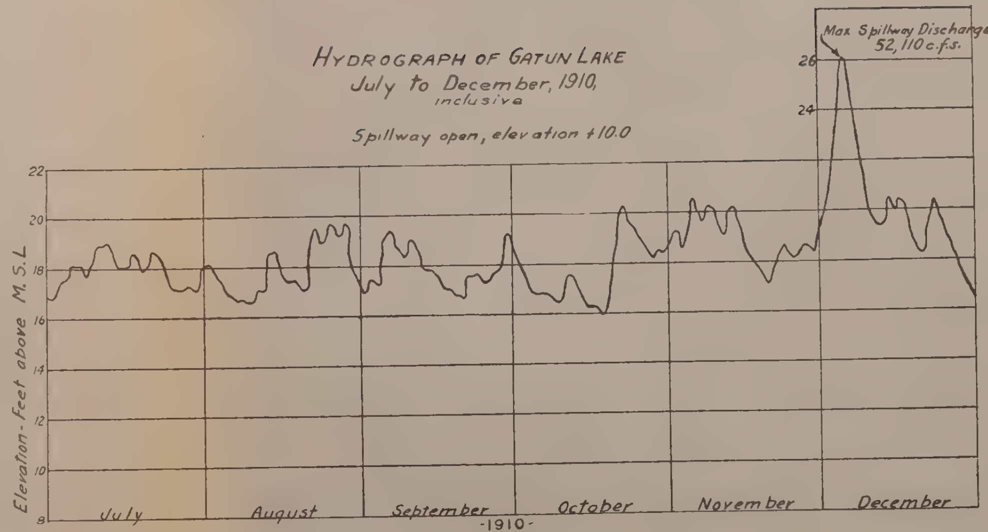

CROSS SECTIONS
CHAGRES RIVER - GAMBOA GAGING STATION
+55.3 Water Level - Dec. 3, 1912.
+48.9 - Water Level - May 24 1913.
+46.6 - Water Level - July 3 1912
+44.6 - Water Level - Dec 14 - 1911
+42.2 - Water Level - May 2, 1912.
South Bank
North Bank
Legend
Dec 14, 1911.
May 2, 1912
July 3, 1912
Dec. 3, 1912.
May 24. 1913
Note - Gaging station abandoned on December, 1912
Elevations in Feet above Mean Sea Level
Distance in Feet from Initial Point
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580

Fig. 52.



HYDROGRAPH OF GATUN LAKE
April to June, 1910.
After April 25, spillway open, elevation +10.0
Elevation above M.S.L.
Filling West Diversion Begins
West Diversion closed
April
May
June
1910



HYDROGRAPH OF GATUN LAKE
July to December, 1910, inclusive
Spillway open, elevation +10.0
Max Spillway Discharge 52,110 c.f.s.
Elevation - Feet above M.S.L.
July
August
September
October
November
December
-1910-

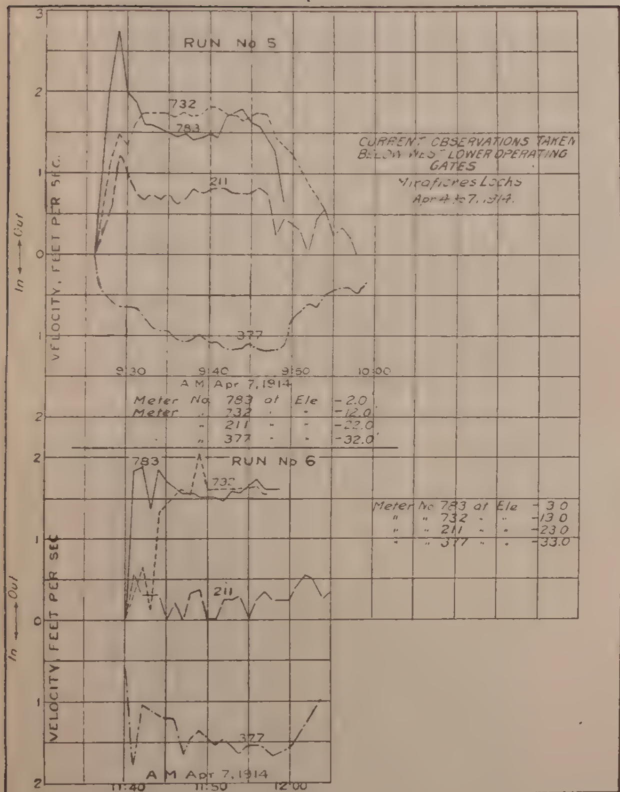
Fig. 53.

TABLE 56.

FRESHETS AT GAMBOA, 1890 to December, 1912, Attaining Elevation 56 or over, and Absolute Maxima of the Periods.

Years	January		February		March		April		May		June		July		August		September		October		November		December		Total	
	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation	Number	Maximum elevation
1890	--	--	--	--	--	--	--	--	5	59.8	4	59.1	[illegible]	60.8	7	59.1	3	62.1	5	63.4	3	62.1	3	*77.8	34	77.8
1891	--	--	--	--	--	--	--	--	2	60.1	1	60.8	2	62.1	--	--	--	--	1	56.2	2	*65.7	2	58.8	10	65.7
1892	--	--	--	--	--	--	--	--	7	63.4	1	58.1	8	62.7	3	62.1	--	--	2	59.1	1	*68.8	2	61.8	24	68.8
1893	--	--	--	--	--	--	2	62.3	2	62.4	--	--	1	57.8	2	59.9	--	--	--	--	1	59.1	6	*71.3	14	71.3
1894	2	63.9	--	--	--	--	--	--	1	56.9	--	--	4	59.8	2	57.8	3	59.9	3	58.5	5	60.1	7	*65.0	27	65.0
1895	1	56.3	--	--	--	--	1	56.0	--	--	1	61.9	1	59.7	2	58.9	--	--	2	*63.1	--	--	1	66.0	9	63.1
1896	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	59.3	--	--
1897	--	--	--	--	--	--	1	56.2	6	*69.0	--	--	--	--	--	--	--	--	1	56.2	3	58.7	4	59.2	--	69.0
1898	2	63.0	--	--	--	--	1	*63.7	--	--	--	--	1	58.6	2	56.3	--	--	2	59.7	3	62.9	--	--	11	63.7
1899	2	60.2	--	--	--	--	--	--	2	59.5	1	56.1	1	56.1	2	62.2	--	--	--	--	2	60.8	--	--	10	62.2
1900	--	--	--	--	--	--	--	--	--	--	--	--	2	57.6	3	59.5	1	57.2	3	*61.1	2	57.9	1	60.1	12	61.1
1901	--	--	--	--	--	--	--	--	1	59.4	1	56.1	--	--	2	56.3	1	57.7	--	--	7	*66.9	1	61.4	13	66.9
1902	3	*62.4	--	--	--	--	1	57.2	--	--	--	--	1	56.1	1	61.1	--	--	2	*62.4	1	57.8	--	--	9	62.4
1903	--	--	--	--	--	--	--	--	--	--	1	56.1	1	64.7	1	62.1	--	--	--	--	3	*66.3	6	59.0	12	66.3
1904	1	60.0	--	--	--	--	2	57.5	--	--	2	59.9	1	56.6	--	--	3	58.8	--	--	3	*64.6	1	56.1	13	64.6
1905	--	--	--	--	--	--	--	--	2	58.7	1	61.4	--	--	1	57.0	--	--	2	*61.9	--	--	--	--	6	61.9
1906	--	--	--	--	--	--	--	--	1	61.5	--	--	4	59.5	1	58.1	1	57.5	--	--	1	68.3	3	*81.7	11	81.7
1907	--	--	--	--	--	--	--	--	1	57.3	1	57.6	1	*62.8	2	56.9	2	57.9	2	57.2	1	59.9	1	62.5	11	62.8
1908	--	--	--	--	--	--	--	--	1	58.6	1	57.9	1	58.5	1	59.4	--	--	4	57.4	6	*60.8	2	59.2	17	60.8
1909	3	56.7	1	64.9	--	--	--	--	3	58.9	5	67.4	1	56.0	3	57.2	2	61.6	1	56.0	4	72.6	5	*78.2	28	78.2
1910	1	57.2	1	56.7	--	--	--	--	2	61.9	--	--	1	56.8	1	60.4	--	--	1	56.1	3	57.9	2	*64.5	12	64.5
1911	--	--	1	58.3	--	--	--	--	--	--	1	57.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1912	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	57.5	--	--	--	--	1	62.4	--	--	--	--
Total Maxima	15	63.9	3	64.9	--	--	8	63.7	36	69.0	21	67.4	35	64.7	36	62.2	16	62.1	31	63.4	51	72.6	48	81.7	298	81.7

* Yearly maxima.


RUN No 5
CURRENT OBSERVATIONS TAKEN BELOW WEST LOWER OPERATING GATES
Miraflores Locks
Apr 4 to 7, 1914.
VELOCITY, FEET PER SEC.
In ← → Out
9:30
9:40
9:50
10:00
A M Apr 7, 1914
Meter No 783 at Ele -2.0
Meter " 732 " " -12.0
" 211 " " -22.0
" 377 " " -32.0
RUN No 6
Meter No 783 at Ele -3 0
" " 732 " " -13 0
" " 211 " " -23 0
" " 377 " " -33.0
VELOCITY, FEET PER SEC
A M Apr 7, 1914
11:40
11:50
12:00

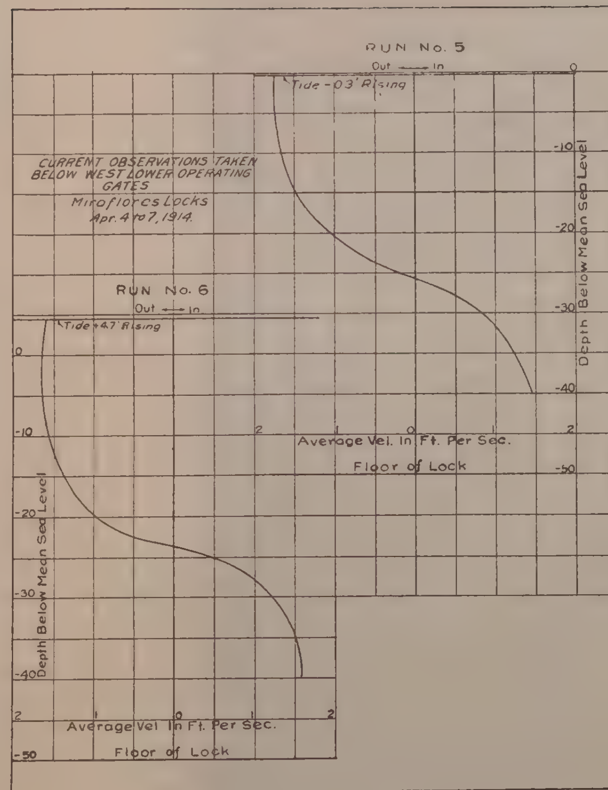

RUN No. 5
Out ← → In
Tide -0.3' Rising
CURRENT OBSERVATIONS TAKEN BELOW WEST LOWER OPERATING GATES
Miraflores Locks
Apr. 4 to 7, 1914.
Depth Below Mean Sea Level
Average Vel. In Ft. Per Sec.
Floor of Lock
RUN No. 6
Out ← → In
Tide +4.7' Rising
Depth Below Mean Sea Level
Average Vel In Ft. Per Sec.
Floor of Lock

Fig. 66.

Study of Relation Between Rainfall and Run-off for Gatun Lake Watershed During Filling of Gatun Lake, May to December, 1913.

The records of rainfall over Gatun Lake watershed cover the period from May, 1901, to December, 1913 (13 years). The rainfall and total run-off (including evaporation from Gatun Lake since May, 1910) have been compiled by monthly averages and

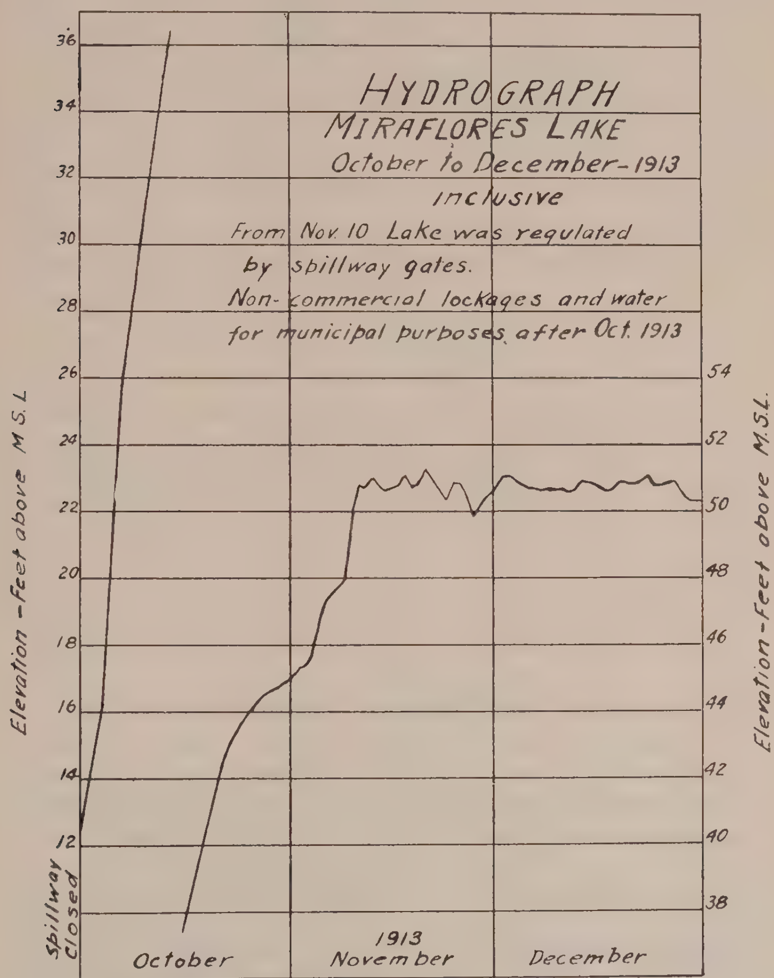


Fig. 58.

the percentage of run-off computed. These data have been plotted both by months and by accumulated quantities from May to December, inclusive.

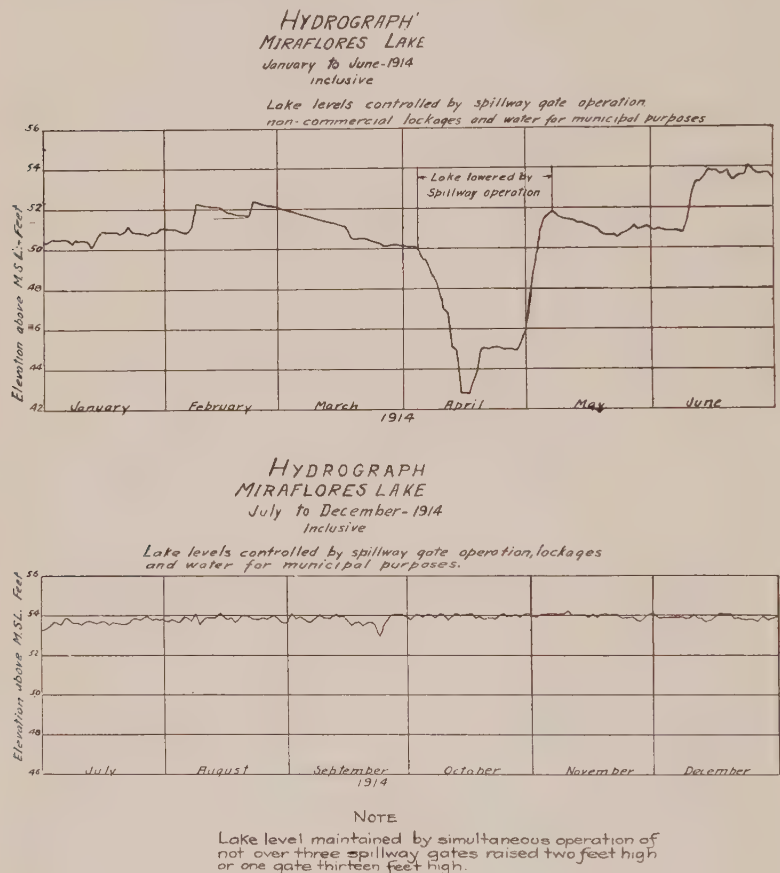


Fig. 59.

The run-off data for the watershed were obtained in the following manner:

May, 1901, to April, 1907, inclusive, Bohio discharge $\times$ 1.62
May, 1907, to April, 1908, " Bohio plus Trinidad plus Gatun River $\times$ 1.10
May, 1908, to April, 1910, " Actual measurements at Gatun
May, 1910, to Dec., 1913, " Actual measurement of total yield, discharge, storage and evaporation.

The ratios 1.62 and 1.10 were determined from the relation of discharge at various stations measured from May, 1908, to April, 1910. Storage was measured by the capacity curve of Gatun Lake and evaporation from data obtained at Gatun and Brazos Brook stations.

Referring to the accompanying Fig. 61, it is obvious that any considerable quantity of seepage or other underground losses would show up in a diminished run-off for 1913. Noting the curves representing accumulated rainfall and run-off it is seen

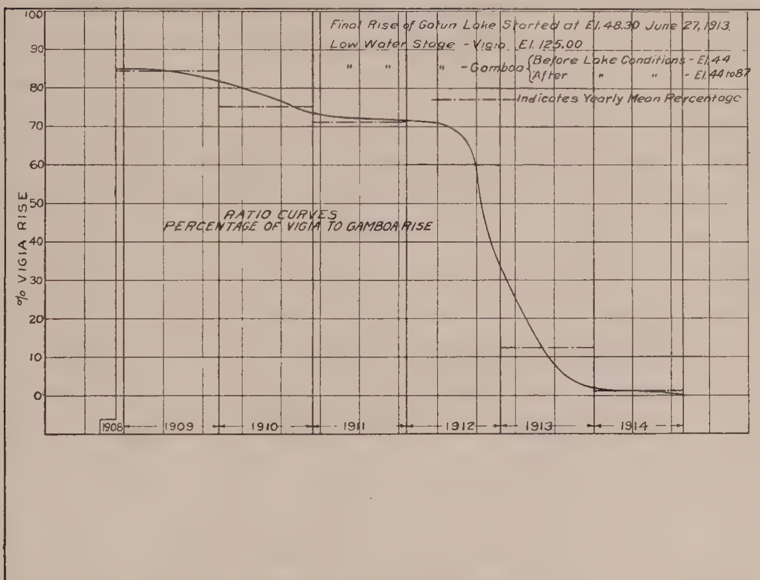


Fig. 60.

that the run-off for May to December, 1913, follows closely the average run-off for these months, except December, when it diminishes. The same is true for the rainfall. This relation between rainfall and run-off is shown directly by the percentage curves which run fairly parallel, the 1913 curve crossing above the average curve during November.

There is one item which must be considered in connection with the run-off for 1913, and that is the gain in run-off for the area now covered by the lake, both on account of the gain by direct rainfall on the lake surface as well as the absence of water

consumed by plant use. The evaporation has been added to the net yield (discharge and storage) to give the total run-off. These facts help to explain the large run-off in November when the area

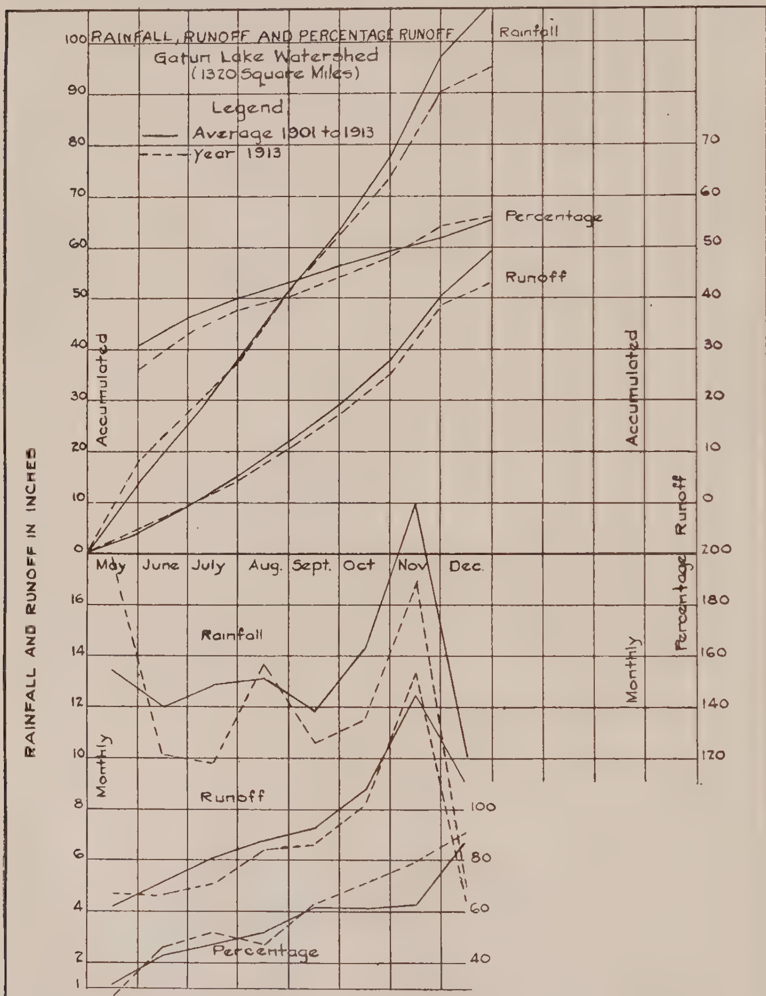


Fig. 61.

of the lake was large and received the most rainfall. Accompanying Fig. 62 gives mass curves for the total yield, net yield, yield of land area, rainfall on lake surface and evaporation in billion cubic feet for May to December, 1913. The difference

between the net and total yield curves is given by the evaporation curve, while the difference between total yield and yield from land area is given by the rainfall curve. A comparison of the

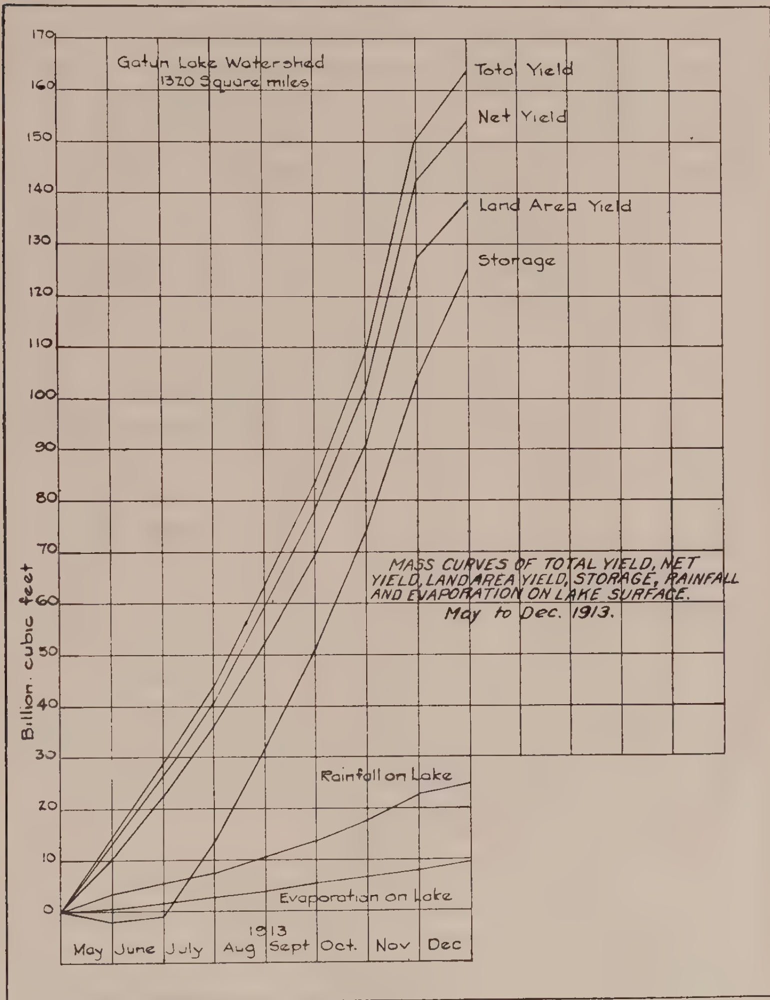


Fig. 62.

rainfall and evaporation curves shows the gain in run-off due to direct rainfall in the lake surface. The storage curve is given to show the period during which the lake was rising.

The gain in run-off due to direct rainfall is shown on Fig. 63. The rainfall curves show the rainfall on the total watershed, land area and lake area. The run-off curves show the run-off

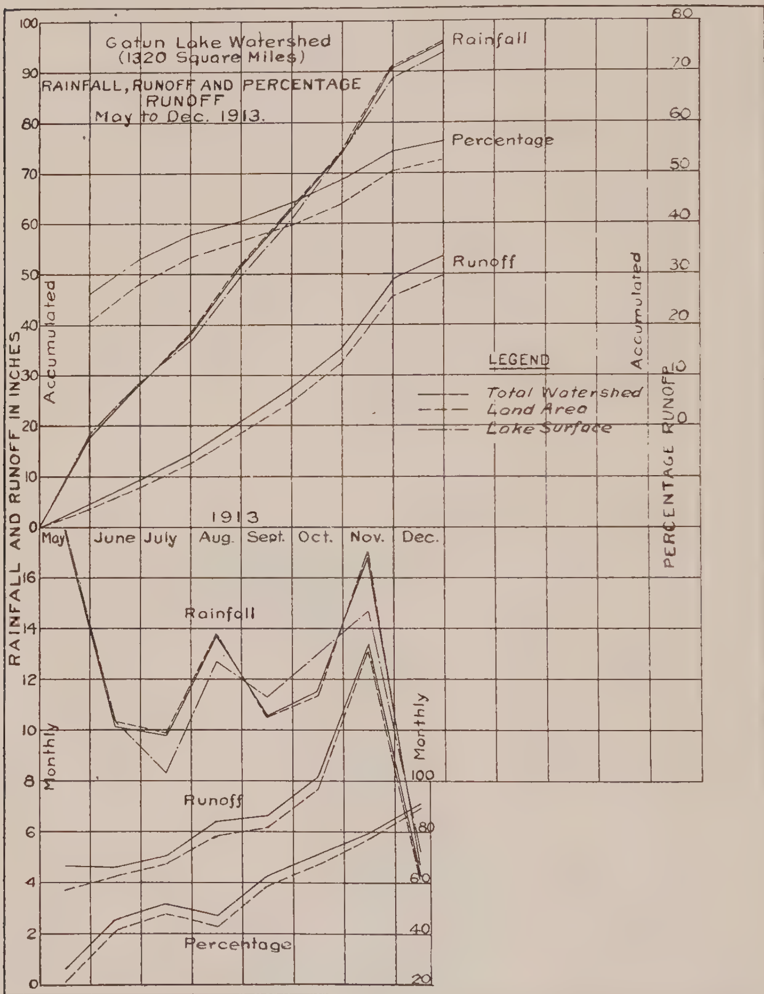


Fig. 63.

from the total watershed and the run-off from the land area. These values are expressed in inches on the area considered, thus eliminating the difference in the amount of run-off due to the dif-

ference in area. The run-off curve for the land area represents the run-off in inches that would have taken place had there been no lake. The total run-off curve shows the gain in run-off in inches. The percentage run-off curves for total area of watershed and land area show this gain. These curves converge, due to the fact that the percentage of run-off from the land area increases through the rainy season and the first part of the dry season, being lowest at the beginning of the rainy season.

Figure 64 gives the actual hydrograph of Gatun Lake for the period from May to December, 1913. The variation in the

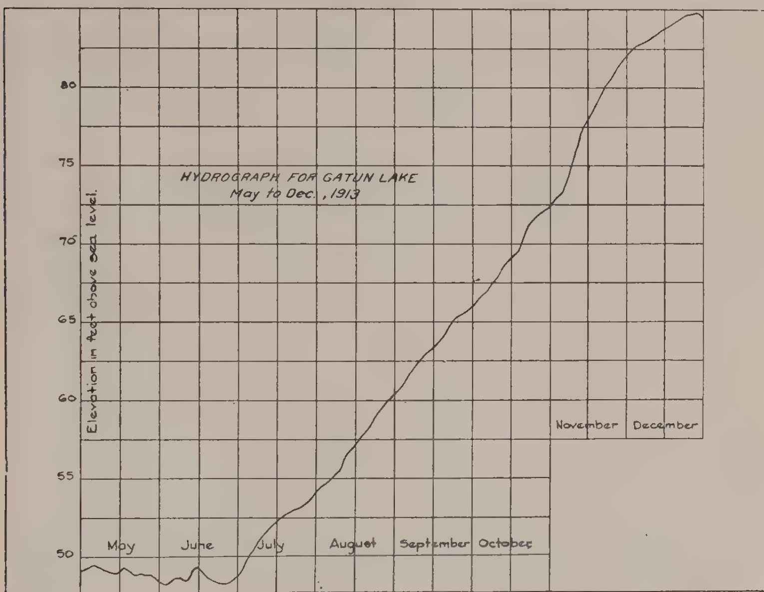


Fig. 64.

level during May and June was due to the regulation of the sluice gates in Gatun Spillway. The Spillway gates were operated on December 27th, 29th, 30th and 31st, causing a fall in the lake. Had the water been stored to the end of December, the elevation would have reached 84.92 feet. The actual period of filling was during the months of July to December, inclusive. During this time the rainfall was 81.8% of the 13-year average, while the run-off was 87.5% of the 13-year average, showing a gain in run-off of 5%, probably due to the direct rainfall on the

Fig. 65. Gatun Lake. Surface of Water at 52.5 ft. above Sea Level, showing the Dying Jungle, December 1912.

lake surface, and showing there has been no loss of any moment from the lake by seepage or other underground passage.

The dry season of 1914 was the first one during which Gatun and Miraflores Lakes were approximately at operating level, thus exposing their maximum surfaces to the influence of evaporation.

The records for the season are therefore indicative of what may be expected in coming years of Canal operation.

The run-off from the watershed of Gatun Lake during the dry season, January to April, inclusive, amounted to 16,953 million cubic feet, or 61% of the normal dry season run-off as determined from the average of 25 years of record. The lake was maintained at approximately normal elevation throughout the season. The total wastage of water through the Spillway amounted to 4,854 billion cubic feet. The amount consumed by lockages to and from the Atlantic entrance was 256 million cubic feet and the amount by lockages, filling, tests and pumping to and from Miraflores Lake, 581 million cubic feet. In addition, 137 million cubic feet were passed through the tunnel at Quebrancha divide for supply to Brazos Brook reservoir.

It is estimated that if none of the water had been allowed to pass out of the lake, except by evaporation, the run-off was sufficient to have raised the surface of the lake to 86.18 feet above the sea-level.

MISCELLANEOUS DATA.

Test Report of Current Observations Taken Below the West Lower Operating Gates, Miraflores Locks, April 4-7, 1914.

During the equalizing of the waters at the lower lock gates at Gatun and Miraflores, an interesting phenomenon is noticed, due to the difference in the density of the water in the lake chamber and the sea-water below. When the lower gates are opened, the fresh water passes out as an upper current, and the denser sea water rushes in as a lower current. The process of equalization continues several minutes.

To determine direction of currents between surface of water and El. —15.0 ft., blades suspended from floats were used. Below El. —20.0 an instrument was needed which could be held rigid and which would indicate any change in direction. A vane 10 inches wide along one half its length, a ½-in. iron rod forming the other half, was fixed at centre, at right angles to a vertical rod which extended through a sleeve to a point above water. Here, a pointer was fixed parallel to the vane. The sleeve in which the vertical rod turned was guyed to the lock walls in such a manner as to facilitate raising and lowering the entire instrument, thus putting the vane into play at any desired elevation, leaving the pointer to be observed at a point above water about 75 feet out from the lower operating gates. (See Fig. 66.)

To determine the velocities of currents at different elevations, four current meters were mounted 10 ft. apart on a ¾-in.

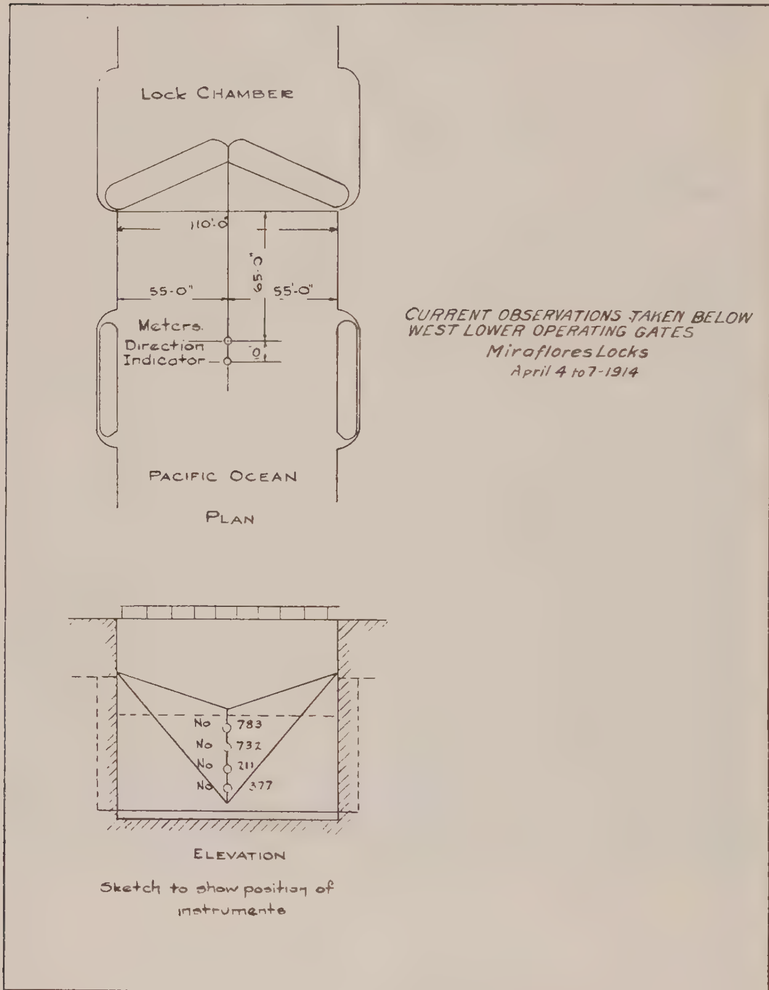


Fig. 67.

pipe which was supported vertically in the centre of the lock at a point about 10 ft. in from the direction indicator. (See Fig. 67.)

Raising and lowering were provided for in a manner similar to that for direction-indicator supports. For convenience we

will speak of the uppermost meter as No. 783, the second below surface as No. 732, the third as No. 211 and lowest meter as No. 377. The time intervals between readings of these meters vary with the type of instrument from 10 seconds to 1 minute, and the velocities given as results of each run are average values calculated from readings taken during that run. Time referred to of opening and closing mitre gates begins with first cracking of gates, and ends with tight joining. In each case gates were opened full, allowed to remain open for about 30 minutes, then closed. The lower guard gates remained open full during all test runs.

Run No. 1.

Tide —2.6 ft.; falling
Meters: No. 783 at El. —7.5 ft., No. 732 at El. —17.5 ft.,
No. 211 at El. —27.5 ft., No. 377 at El. —37.5 ft.
Direction Indicator at El. —37.5 ft.

The flow of water through the culvert from the lock chamber to sea, in equalizing, caused the direction indicator vane to fluctuate rapidly, due to eddies set up. This was reassuring with respect to adaptability of the instrument.

Lower operating gates opened at 2:36 P. M., closed 2:52 P. M.
Direction of current at El. .... —5.0 ft. and —10.0 ft. out
" " " " " .... —37.5 ft. in (towards locks)
Average Velocities: " " .... —7.5 ft., 2.00 ft. per second
" " " " .... —17.5 ft., Meter not recording due to effect of salt water on contact points.
" " " " .... —27.5 ft., 1.06 ft. per sec.
" " " " .... —37.5 ft., 1.66 " " "

Run No. 2.

Tide +1.4 ft.; rising
Meters: No. 783 at El. —5.0 ft., No. 732 at El. —15.0 ft.,
No. 211 at El. —25.0 ft., No. 377 at El. —35.0 ft.
Vane of Direction Indicator at El. —30.0 ft.

Lower operating gates opened at 9:18 A. M., closed at 9:45 A. M.
Direction of current at El. .... —5.0 ft. and —10.0 ft. out
" " " " " .... —30.0 ft. in
Average Velocities: " " .... —5.0 ft., 1.79 ft. per sec.
" " " " .... —15.0 ft., 1.85 ft. per sec.
" " " " .... —25.0 ft., 0.5 ft. per sec.
" " " " .... —35.0 ft., 2.04 ft. per sec.

Run No. 3.

Tide +2.3 ft.; falling
Meters: No. 783 at El. —5.0 ft., No. 732 at El. —15.0 ft.,
No. 211 at El. —25.0 ft., No. 377 at El. —35.0 ft.
Indicator Vane at El. .... —25.0 ft.

Lower operating gates opened at 2:06 P. M., closed at 2:35 P. M.

Direction of currents at El. .... —5.0 ft. and —10.0 ft. out
" " " " " .... —25.0 ft. in
Average Velocities: " " .... —5.0 ft., 1.77 ft. per sec.
" " " " .... —15.0 ft., Meter not working due to effect of salt water on contact points.
" " " " .... —25.0 ft., 0.61 ft. per sec.
" " " " .... —35.0 ft., 1.89 ft. per sec.

Run No. 4.

Tide —2.2 ft.; falling
Meters: No. 783 at El. —3.0 ft., No. 732 at El. —13.0 ft.,
No. 211 at El. —23.0 ft., No. 377 at El. —33.0 ft.
Indicator Vane at El. .... —20.0 ft.

Lower operating gates opened at 4:23 P. M., closed at 4:54 P. M.

Direction of current at El. .... —5.0 and —10.0 out
" " " " " .... —20.0 ft. out
Average Velocities: " " .... —3.0 ft., 1.56 ft. per sec.
" " " " .... —13.0 ft., 1.58 ft. per sec.
" " " " .... —23.0 ft., 0.89 ft. per sec.
" " " " .... —33.0 ft., 1.28 ft. per sec.

Run No. 5.

Tide —0.3 ft.; rising
Meters: No. 783 at El. —2.0 ft., No. 732 at El. —12.0 ft.,
No. 211 at El. —22.0 ft., No. 377 at El. —32.0 ft.
Indicator Vane at El. .... —25.0 ft.

Lower operating gates opened at 9:26 A. M., closed at 9:58 A. M.

Direction of currents at El. .... —5.0 ft. and —10.0 ft. out
" " " " " .... —25.0 ft. out
Average Velocities: " " .... —2.0 ft., 1.65 ft. per sec.
" " " " .... —12.0 ft., 1.71 ft. per sec.
" " " " .... —22.0 ft., 0.75 ft. per sec.
" " " " .... —32.0 ft., 1.08 ft. per sec.

Run No. 6.

Tide +4.7 ft.; rising
Meters: No. 783 at El. —3.0 ft., No. 732 at El. —13.0 ft.,
No. 211 at El. —23.0 ft., No. 377 at El. —33.0 ft.
Indicator Vane at El. .... —25.0 ft.

Lower operating gates opened at 11:40 A. M., closed at 12:05 P. M.

Direction of currents at El. .... —5.0 ft. and —10.0 ft. out
" " " " " .... —25.0 ft. in
Average Velocities: " " .... —3.0 ft., 1.60 ft. per sec.
" " " " .... —13.0 ft., 1.53 ft. per sec.
" " " " .... —23.0 ft., 0.27 ft. per sec.
" " " " .... —33.0 ft., 1.46 ft. per sec.

On a vertical base line, velocity in is plotted to right and velocity out, to left. The vertical depth from mean sea-level to El. —50.0 ft. or floor of lock is the ordinate; for instance, in Run No. 1, the direction of current determined by float is out, at El. —7.5 ft., and velocity at this elevation is 2.00 ft. per second. Therefore, going down the vertical base line from 0 to ––7.5 ft. and horizontally to left, the point on the curve is struck. These six curves show that at some point between El. —20.0 ft. and —30.0 ft. the velocity is zero. In Runs 1, 2, 3, and 6, this neutral point is about El. —24.0 ft. and in Nos. 4 and 5, a little lower.

For Runs Nos. 5 and 6, which are typical, time intervals of one minute are plotted left to right. Feet per second, velocity at each minute is plotted up when direction is out, and down when direction is in. It has been assumed from the test runs, that, at a given elevation, the direction of current is the same for all operations of gates, and this assumption was used in plotting curves. It will be noted in comparing these curves for Runs Nos. 5 and 6 that Meter No. 211 in Run No. 5, at El. —22.0 ft., shows a velocity running above 0.6 ft. per second out. But, in Run No. 6, with Meter 211, at —23.0 ft., which is nearer the neutral point shown by the curves of the six tests, the velocity is less than in Run No. 5, and drops to zero in four readings. This substantiates the results obtained with respect to the elevation of the point of zero velocity.

The Filling of Culebra Cut, October 10, 1913.

Prior to October 10, 1913, the waters of the Chagres River were kept from entering Culebra Cut by means of an earth dike

72 feet high across the Canal at Gamboa. Prior to the explosion, water was admitted to the Cut through pipes, in order to reduce the head.

At 2:00 P. M. the elevation of Gatun Lake at Gamboa water-stage register was 67.72 ft. and the gage in Culebra Cut recorded 61.90 ft., giving a head of 5.82 feet in the dike at the time the explosion occurred (2:03 P. M.). The wave passed the gage staff located about 3000 feet south of the dike at 2:07 P. M. with a maximum elevation of 63.20 feet, making the elevation of the wave at this point 1.3 feet. The elevation fell to 62.8 feet at 2:10 P. M., followed by a gradual rise until 4:15 P. M. The levels on either side of the dike were equalized at elevation 67.9 ft. The rise at Empire bridge began at 2:16 P. M. The rise was gradual and no large wave was observed.

The rise at Cucaracha began at 2:21 and at 2:25:10 the elevation had reached elevation 63.04 ft., from which it fell to elevation 62.69 ft. at 2:25:40 P. M., after which the rise was fairly steady until 4:15 P. M. No large wave was observed at this station.

The water in the Cut and in the vicinity of Gamboa water-stage register, located about 1300 feet east of the east end of Gamboa dike, was about 0.2 feet higher than the main body of water in Gatun Lake at 4:15 P. M., due to inertia of the flow from the lake following the explosion and the reflex action of the water in the Cut.

Following the explosion, the elevation at Gamboa water-stage register dropped to 67.43 ft. at 2:30 P. M. Two hours later it had risen to 67.91 ft., from which elevation it gradually fell until 7:00 P. M., when the gage registered 67.71 ft. From 7:00 P. M. the water rose gradually until 10:00 P. M., when elevation 67.76 ft. was recorded, at which elevation it remained until 7:00 A. M., October 11th. Similar effects are shown at the other stations, but the fluctuations are less, being governed by the distance from Gamboa.

The filling of the Cut from elevation 61.90 ft. to 67.72 ft. represented about 62 million cubic feet of water, or a depth of 0.02 feet in Gatun Lake at elevation 67.72 ft.

With Gatun Lake at elevation plus 85 feet, to fill Culebra Cut would reduce the lake level 0.20 of a foot.

Paper No. 10

THE DRY EXCAVATION OF THE PANAMA CANAL.

By

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The French Company, engaged in the construction of the Panama Canal, in order to retain the concession secured from the Republic of Colombia, continued work up to the time it transferred its rights and properties to the United States, in May, 1904. Due to lack of funds, the working force had dwindled to approximately 800 men, and these were engaged almost exclusively in continuing the excavation of the prism through the continental divide, or that section known as Culebra Cut* and commonly called "The Cut".

Work in this locality was begun by the Compagnie Universelle du Canal Interoceanique, and continued by the New Panama Canal Company, which was organized on the failure of the former. This section extends from Gamboa on the Chagres River at the north, to Pedro Miguel on the south, and covers a length of 8.75 miles. The summit of the divide was between Gold Hill on the east and Contractor's Hill on the west; the top of the former is at elevation 540 above sea level, and of the latter 410 feet above the same datum. The lowest point in the saddle between these two hills was at elevation 333.5 above sea level. The canal prism took in nearly all of the saddle, therefore parts of the two hills. The general profile along the axis of the Cut is indicated in Plate I.

After removing the peak of the divide and lesser summits, the French attacked the Cut in the direction of its length, en-

*By Executive Order of April 27, 1915, the name "Culebra Cut" was changed to "Gaillard Cut".

abling the simultaneous use of a number of excavating machines, so that a succession of trenches resulted, lying one above the other, each with the natural surface of the ground as a point of beginning. The cross-section of the resulting excavated area thus appears as a series of steps each about 16 feet high, the depth to which the excavators could work, and of sufficient width for the excavator and track for the train which served it.

The equipment in use by the French consisted of excavators mounted on trucks. On the body of the car was a frame supporting a ladder which projected over the side, with a tumbler at either end, about which worked an endless chain carrying buckets of a capacity of 6 cubic feet. The contents of the buckets were dumped into a hopper supported just below the upper end of the ladder from which, by means of a chute, the material was loaded into cars alongside the excavator. The locomotives varied in weight from 28 to 38 tons, with a drawbar pull of 11,000 pounds in the former and 14,450 pounds in the latter. The cars were six-metre cars holding 4½ cubic metres of material in place. There was also a large number of dump buckets of 1½ cubic metre capacity which were handled by cranes mounted on trucks. In addition, there was in use a system of cableways, consisting of four cables of American manufacture and two of French, handling buckets of one cubic metre capacity. These cableways extended across the Cut, supported by towers on either side; the buckets were filled by hand, and were then drawn to the bank of the Cut and dumped into cars. The French resorted to a large amount of task work, which was performed by West Indian negroes; each man was required to do a specific amount of work per day, could utilize his own time in doing it, and do as much more as he saw fit. The work was paid for by the bucket. The rails used were 60 pounds to the yard, and recourse was had to both wooden and metal ties. The gauge conformed to that of the Panama Railroad, or 5 feet.

When the United States assumed control, the two French companies had removed from the Cut a total of 18,646,000 cubic yards of material, of which 7,271,940 cubic yards were classified as rock and the balance as earth, principally clay. The

highest point in the excavated area, or the summit of the Cut, was near Gold Hill and at reference 193 above sea level. With the transfer of the French rights and properties, the United States forces continued the excavation through the divide, utilizing the equipment in use and making available such other tools and appliances as were suitable for the purpose. Great advances had been made in excavating machinery, and steps were at once taken to replace the excavators by the heaviest and latest types of steam shovels procurable. The main problem that the excavation of Culebra Cut presented was one of transportation—getting the excavated material from the shovels to the spoil banks; so steps were taken to provide heavier engines and larger cars, with heavier rails. An enormous amount of preliminary work had to be done before the excavation of the Culebra Cut could proceed on a scale that would insure its completion within a reasonable time, and to the thoroughness with which this preliminary work was done is attributable the success subsequently attained. The distance from the source of supply necessitated the shipment of steam shovels, cars and locomotives in a knocked-down condition, and their subsequent assembling and re-erection on the Isthmus. For this purpose, existing shops were overhauled, rehabilitated and extended, and new ones were built. The Panama Railroad, which had deteriorated, due to lack of funds for its proper maintenance, was put in first-class condition, provided with heavier rails, and double-tracked for nearly its entire length. Roundhouses were built, yards constructed, the construction tracks in the Cut were thoroughly overhauled, ballasted, and 70-pound rails substituted.

Cutting the prism of the canal through the continental divide was the most formidable part of the canal enterprise, due to its magnitude, the relatively contracted space within which the operations had to be conducted, the heavy rainfall, and the natural difficulties that were encountered and had to be overcome.

The line of the canal follows the valley of the Chagres River to the mouth of the Obispo River. This stream has its source east of Gold Hill, and measured along the center of Culebra Cut was five miles long; it drained an area of approximately 4.42 square miles. The canal line followed the valley

of the Obispo, crossing it ten times, to the continental divide, and after leaving this, passed to the Pacific through the valley of the Rio Grande. The Obispo River had four principal tributaries—the Masambi and Sardanilla Rivers from the east, and the Mandingo and Camacho Rivers from the west. The average rainfall for the Culebra section is 79.05 inches, falling in eight or nine months of the year. Whatever rain was not carried off by the streams, entered the Cut, either through direct fall over the excavated area or by seepage into it. Proper drainage was, therefore, an ever-existing problem, and one of the natural difficulties to be overcome. Two distinct phases were presented: (1) To keep out the water of the surrounding country, and (2) to rid the excavated area of the water that collected in it.

The French had undertaken the construction of diversion channels, one on either side of the excavated area, to take care of the water of the surrounding country. On the east side, a ditch carried the water to points nearly opposite Las Cascadas, where it was intended to construct an aqueduct by which to carry it across the Cut into the diversion channel to be constructed on the west side; existing plans also indicate a project for carrying the stream lying south of this aqueduct by a tunnel through the La Pita ridge, thus carrying the water well back from the Cut. On the west side, a ditch carried the water from Empire to Las Cascadas, and at this place it poured into the Cut. The projected plans provided for extending the ditch to Bas Obispo, where it would enter the Obispo River, which joined the Chagres to the west of the Cut. Between Haut Obispo and Bas Obispo the river was deflected sharply by a hill, and through it the French cut a tunnel to divert the stream, thus protecting the excavated area; but it had not been connected up. The tunnel is 420 feet long, 16 feet high from the floor to the crown of the arch, with a minimum cross-section of 100 square feet.

The sea-level canal, as projected by the French, contemplated a bottom width through the Cut of 72 feet. With the canal adopted by the United States of a bottom width of 200 feet and a depth of 45 feet, a considerable change in the existing diversion channels was made necessary, and as carried out

there was a channel on either side—the Obispo diversion on the east and the Camacho on the west.

The Obispo diversion was constructed to carry the largest recorded flow in forty-eight hours, which was 6000 second feet. Its length was 5.5 miles, and the minimum width of channel was 50 feet. Beginning near Gold Hill opposite Culebra the diversion ran along the east side practically parallel to the canal until opposite Haut Obispo, where it was carried around the hills bordering the Cut through a saddle or depression, and emptied its waters into the Chagres one-half mile above Gamboa and about one mile from the crossing of the canal and the Chagres. The construction of the Obispo diversion involved excavating 1,078,000 cubic yards of rock and earth, building 1½ miles of dikes, driving sheet piling along 896 feet of the dikes, and building 1.6 miles of trestles from which earth was dumped to make the dikes, the material having been obtained from the line of the diversion and from the Cut.

Because of its proximity to the Cut, this diversion gave a great deal of trouble, and was undoubtedly responsible for some of the slides which developed. These movements necessitated several changes in the location of the channel, particularly in the section lying between points opposite Culebra and Las Cascadas; these changes required the handling of 155,376 cubic yards of material. In May, 1910, it caused the breaks which occurred at La Pita Point, and the subsequent break north of La Pita Point on August 20, 1912, at which time the Cut to the north was so completely flooded as to stop all excavation for three miles during the remainder of the wet season. To keep the water in the diversion out of the Cut after the break of May, 1910, it was necessary to build a concrete flume around La Pita Hill; it was 400 feet long, 22 to 24 feet wide at the bottom, and the overall height of the wall next to the Cut was 9 feet, giving an inside channel height of 7 feet. Subsequent to the break in the diversion on August 20, 1912, a relocated channel was dug, requiring the excavation of 76,004 cubic yards of material. When dry excavation in the Cut was stopped, and after water from the lake had been admitted to it, the diversion was tapped at six places and the water from the east side now flows into the Cut.

The work done by the United States on the west side of the canal consisted in the creation of a reservoir for water supply to the settlements at Empire and Culebra by the construction of a dam, with a suitable spillway, across the upper valley of the Camacho, which took care of part of the discharge of one of the streams; in joining the existing diversion ditch at Las Cascadas with the Obispo River at Haut Obispo; revetting the sides of the ditch where it runs near the Cut; and cleaning out the tunnel and the ditch between the south end of the tunnel and the Obispo River. About 85,000 cubic yards of material were excavated and 4748 square yards of stone revetment laid.

On the south slope of the divide, the only stream that crossed the line of the canal within the limits of Culebra Cut was the Rio Grande. The French built a dam across this valley, half a mile from the Cut, thus partially impounding its waters; the surplus passed over a spillway into a diversion channel paralleling the Cut, 1.7 miles long, to the old riverbed to the south. The dam was raised in 1907, and the reservoir created thereby furnished water to the adjacent settlements; the overflow was taken care of through the French diversion. After water was admitted to the Cut, an opening was made in the east embankment, thus allowing the overflow to discharge directly into the canal, and removing the danger that might result from the diversion.

The water that collected in the excavated area was carried off by gravity until the depth of the Cut necessitated the use of pumps for handling the water that flowed to them by gravity. The excavation done by the French was up grade from either end, and the water that fell or seeped in north of the summit flowed to the Chagres River, while that on the south slope flowed to the Rio Grande. The work done by the United States was carried on in the same manner, the gradient and the summit in the Cut being fixed in such a way as to provide proper, prompt and efficient drainage. The reference of the low-water surface of the Chagres was 43, at the point of its intersection with the center line of the canal. The bottom of the completed canal is 40. During construction a dike at elevation 71 feet was left to keep out the waters of the Chagres, but this was

overtopped once and broke once during a flood. The dike was subsequently raised to 78.2 feet, as the lake was formed, and maintained at this elevation until October 10, 1913, when it was partially destroyed and the water in the Cut raised to the level of the water in Gatun Lake. To take care of flood waters that might enter the canal, six 24-inch pipes were laid through the dike, two at elevation 46, two at 52, and two at 56, each with a suitable valve. All water above 52 was, therefore, carried into the Chagres by gravity after subsidence of any flood. To remove the remainder, or when there was no flood, to remove what flowed to the north end by gravity, pumps were installed as they were required. At the end of the dry excavation period the following pumping equipment had been provided:

Three duplex pumps, 16 in. by 22 in. by 18 in., capacity 4200 gallons per minute each.

Two Wagner pumps, 16 in. by 18 in. by 12 in., capacity 445 gallons per minute each.

One Worthington centrifugal pump, 24-in. discharge, capacity 18,000 gallons per minute.

Two French centrifugal pumps, capacity 7000 gallons each per minute.

Subsequent to the installation of the above, or in August, 1912, two French centrifugal pumps, capacity 7000 gallons each per minute, were added to the plant.

As already noted, drainage to the south was to the Rio Grande River, and was to continue until it could be turned through one of the culverts of the Pedro Miguel locks. This was delayed, due to change in lock plans necessitating considerably more work, both excavation and concrete, than was originally contemplated; the construction of the Pedro Miguel dam across the valley of the river could be delayed no longer, so recourse was had to pumping for a period of six months. A sump was dug to collect the water for the intakes, and the pumps installed, about March 1, 1911, consisted of two 16-inch centrifugal, three 10-inch centrifugal, one 12-inch centrifugal, one 6-inch centrifugal, one 10-inch Therion, one 8-inch Wagner, and one 6-inch Wagner, with a capacity of approximately 38,250 gallons per minute.

The operations connected with the removal of material

from the canal prism consisted of drilling, loading with explosive, blasting, excavation by steam shovel or other equipment, transportation, and operations at the dumps.

The steam drills turned over by the French were replaced as new ones could be secured, and these were of the tripod and churn or well-drill types. The tripod drills were fitted for working with air at 90 pounds pressure, and those in general use were fitted with $3\frac{5}{8}$-in. cylinders to drill 24-ft. holes 2 in.

Fig. 1. Culebra Cut, Culebra. Air Drills on Side of Contractor's Hill, Looking South. January 1912.

to 3 in. in diameter; others were provided with cylinders varying from $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. in diameter, capable of drilling holes from 10 ft. to 30 ft. deep, with diameters varying from $1\frac{1}{4}$ in. to $3\frac{1}{2}$ in. In addition, one-man portable pneumatic air drills were purchased for drilling holes in masses of rock too large to "dobe" blast, preparatory to breaking up by small charges, and to trim off the side slopes. The two sizes in general use had $1\frac{3}{4}$-in. diameter cylinders drilling $1\frac{3}{4}$-in. holes 3 ft. deep, and $\frac{3}{4}$-in. holes 6 in. deep; two special types were also used, one with a $1\frac{5}{8}$-in. cylinder for holes 20 in. to 36 in. deep, $1\frac{1}{4}$ in.

diameter, and the other with 1-in. cylinder to drill holes 36 in. deep, ¾ in. in diameter.

Over 200 churn or well drills were purchased and used at various points along the route of the canal where dry excavation was in progress, and this type did the greatest part of the drilling in Culebra Cut. They were equipped with boilers and engines, and were capable of drilling holes 5 in. in diameter and 100 ft. deep. Those in use in Culebra Cut were operated by air;

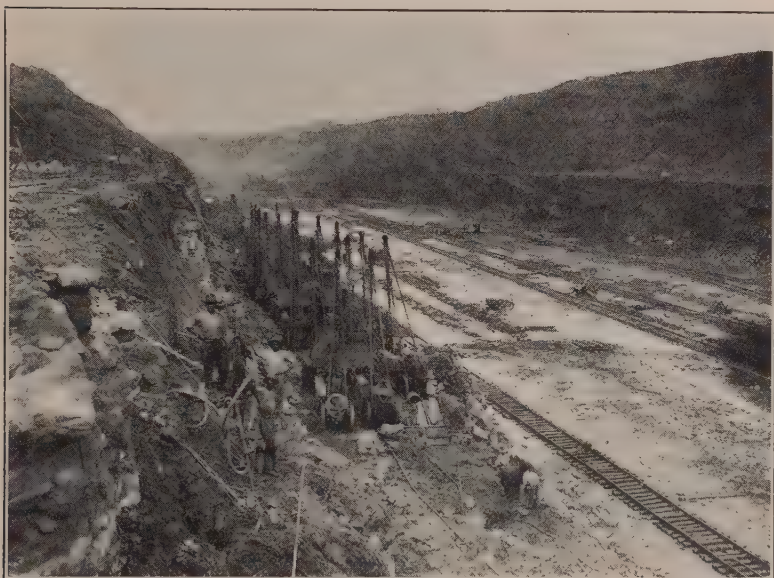


Fig. 2. Culebra Cut, Culebra. Looking North from West Bank. Well Drills on Last Ledge on Bottom of Canal. August 1913.

in isolated localities, where compressed air was not available, the steam apparatus was utilized.

Arrangements were made early in 1905 for the purchase and installation of air compressors to operate the drills in the Cut, and there resulted three plants, one at Rio Grande, one at Empire, and one at Las Cascadas. The Rio Grande air compressor plant was established in 1907, and equipped with two Ingersoll-Rand "Imperial", type 10, compressors, capacity 2500 cubic feet of air per minute each, compressing to 105 pounds gauge; two Laidlaw-Dunn-Gordon Company compressors, with

capacity the same as the foregoing. In 1909 the plant was increased by the addition of one more Ingersoll-Rand compressor, with the same capacity as the others. The compressors were operated by six 250-hp. horizontal, return tubular Robb-Mumford oil-fired steam boilers. The Empire air-compressor plant was established at the same time as the Rio Grande plant, and practically similar equipment was installed, except that twelve boilers were used, six of which were required in connection with the electric plant. The same increase was made in 1909 as at the Rio Grande plant. The Las Cascadas air-compressor plant was established in 1907; the equipment consisted of two Ingersoll-Rand "Imperial", type 10, compressors, capacity of each 2500 cubic feet of air per minute, compressing to 105 pounds gauge, and two Laidlaw-Dunn-Gordon Company compressors of the same capacity. These compressors were operated by six 250-hp. horizontal, return tubular Phoenix oil-fired steam boilers. A 10-in. pipe, with 4-in. and 6-in. leads running into the canal prism, along the west bank, connected these plants.

The supply of water to the steam shovels and compressed air to the well and tripod drills working in Culebra Cut constituted a considerable problem, with the shovels and drills constantly moving forward, and with the change in elevation as the excavation advanced. An indispensable part of the digging of Culebra Cut was the furnishing of a constant supply of water and compressed air, and this duty was assigned to a special section of the division organization, which did no other work. Water was supplied from the reservoirs at Rio Grande and Camacho, and from various pumping stations established especially for the purpose, and air from the compressor plants. A common method was used in distribution.

Culebra Cut is, roughly speaking, 8½ miles long. A parallel system of air and water mains, with 6-, 8- and 10-inch pipes, was run along each side of the Cut, and the mains were so connected as to make a complete circuit around the 8½ miles of excavation, with a connection half way. At intervals of about 1500 feet, gate valves were placed, by means of which the water or air could be shut off from any section of the circuit without cutting off the supply from the remaining sec-

tions. At intervals of 500 feet, lateral mains of 6-, 4- and 2-inch pipes were run from the supply mains over the edge and into the Cut; these likewise were supplied with gate valves, and at their free ends were connections to which pipe or hose could be attached to carry water or air to the shovels or drills. In all, there were 181,200 linear feet, or 34.31 miles, of 6-, 8- and 10-inch air and water mains in use, and 45,300 feet, or 8.6 miles, of lateral drop pipes. An average of 400,000 linear feet, 75.7 miles, of supply pipes to the drills and shovels from the lateral drops, was taken up and relaid monthly. One of the frequent causes for moving the mains was the slides. In the latter part of 1911 the gradual breaking away of a part of the bank made it necessary to move back both the air and water mains a distance of several hundred feet from the edge of the Cut. Other similar removals, which amounted to taking up and relaying whole sections of the mains, were necessary; yet on account of the system of maintaining two complete circuits, these removals never delayed the work.

The drills were operated generally in batteries of from four to sixteen drills, covering a width of from 30 to 50 feet; the holes, from 15 to 30 feet in depth, were spaced from 6 to 16 feet apart. The distance apart and the number of drills in a battery depended upon the character of the rock encountered. Subsequent to January, 1911, when it was thought that heavy blasting had a tendency to induce slides, the holes were limited as a rule to a depth of 15 feet.

The sharpening of drills and miscellaneous small blacksmith jobs were done at first in shops located at Rio Grande, Paraiso, on the west bank opposite Cucaracha, Empire, and at Whitehouse (near Cascadas), but as the Cut was deepened, facilities more accessible became necessary. The shops on the upper level gradually disappeared and were moved to the Cut proper. These consisted of three small stationary shops, one in each construction district, and of flat cars, on each of which were mounted necessary forges, dies, hammers, etc., operated by compressed air. The cars were moved from point to point as needed.

Loading the holes and blasting followed the drilling. Conditions on the Isthmus with reference to mining operations were

peculiar; in the first place, because of the magnitude of the work necessitating the handling in the Central Division during the height of the work of 700,000 pounds of dynamite and the exploding of 260,088 feet of holes each month; in the second place, because the material excavated was not uniform, and the powder men and the steam shovel men found themselves handling the hardest rock one hour, while the next hour they might be working in earth or clay.

By far the greater amount of explosives used for the dry excavation of the prism consisted of 45% and 60% nitroglycerin saltpeter dynamite, though during the early period of the work some dynamite of other grades was used, and also a small quantity of black powder. The black powder was not efficient during the wet season on account of water which accumulated in the drill holes, and its use was, therefore, discontinued.

In June, 1908, a trial shipment of 50,000 pounds of Trojan powder was received and tested with very satisfactory results; consequently, in 1909, when it was apparent that the price of dynamite was steadily increasing, due possibly to a combination between manufacturers, the following clause was inserted in our advertisement for explosives:

> "Alternative bids may be considered for Trojan or for similar powder equivalent in disruptive effect to the grades of nitroglycerin dynamite heretofore specified and similarly packed."

Under this provision, a considerable quantity of Trojan powder was purchased from time to time, and proved satisfactory. It was found unsuitable for subaqueous work; but, unlike dynamite, it did not require turning while in storage, and it was considered safer to handle.

In 1913 the claim was put forward by certain manufacturers of dynamite that Trojan powder was not "equivalent in disruptive effect" to similar grades of dynamite, and that therefore the canal could not legally pay the full contract price for the Trojan powder. Investigation was made, and while the claims of the dynamite manufacturers appeared to be true so far as the laboratory tests were concerned, a committee which was appointed on the Isthmus to witness the results of practical tests reported that for the general classes of material along the

line of the canal, Trojan powder gave results as satisfactory and efficient as those attained with equal grades of dynamite. Explosives were put up in cartridges 2 in. in diameter and 8 in. long, each weighing ½ pound. The cartridges were packed in wooden boxes of 50 pounds.

The dynamite was brought to the Isthmus in steamers especially chartered for the purpose, unloaded at Cristobal until a dock constructed at Mindi on the French canal four miles from Cristobal could be made available for the purpose, and taken by special trains to magazines located at some distances from the line of the work, so that as little damage as possible would result in case of accidents. There were at first four of these magazines; one at Mindi, one and one-half miles from the main line of the Panama Railroad; one up the Chagres River, one mile from Gamboa; one northeast of Gold Hill; and one on the southwest of Cocoli Hill. The one near Gold Hill was subsequently abandoned.

Service magazines, capable of holding about a week's supply, were located at various points accessible to the work; those for Culebra Cut, four in number, were on the east side. The magazines, both general and service, were constructed of hollow concrete blocks and were designed to be bullet-proof; each was in charge of a watchman, and the ground for some distance around the magazine was kept clear of all rubbish and free of vegetation so far as practicable, so as to avoid the possibility of fire. The temperatures of the magazines were carefully watched; the boxes turned periodically—in short, stringent regulations governing the care and handling of dynamite were enforced with a view to reducing the chances of accident to a minimum. The fuses were kept in separate houses in the vicinity of the service magazines, similar in construction to the latter. The dynamite was sometimes carried to the Cut by push cars, but more generally by laborers, each taking one box.

Early in 1907, a premature explosion occurred in the Cut in the vicinity of Rio Grande. An investigation developed that the rammer was of lignum vitae, or cocabola, to the weight of which in falling was attributed the accident, and light pine rammers were substituted. Notwithstanding this change, premature explosions occurred, until, in loading a hole, part of a car-

tridge ignited and burned; an investigation showed a sufficiently high temperature in some of the holes to cause ignition or explosion; subsequently the temperature of all holes was taken before loading. A number of accidents resulted from steam shovels coming in contact with unexploded charges, which led to an investigation of the fuses and the results obtained from various methods of firing. Previous to that time charges were exploded by a magneto electric machine, and investigation showed that failures were liable to result when this type of machine was used, whether the fuses were connected up in series or in multiple arc. Experiments were then made by using the current from the lighting plants distributed along the east side of the Cut, and it developed that while misfires occurred where the fuses were connected in series, there were no misfires when the fuses were connected in multiple arc. As a consequence, electric conduits were laid from the various power plants into the Cut, distributed lengthwise through it within easy reach of the areas remaining to be excavated; thereafter all loaded holes were exploded by means of the electric current from the dynamos.

One rather serious accident occurred in the Chagres Section during an electrical storm, caused by induction. Subsequently, no fuses were connected up during a storm or when one was approaching. The most serious accident happened in the vicinity of Bas Obispo through a premature explosion, on the morning of December 12, 1908, resulting in the death of 23 men and the more or less serious injury of 40 others. Fifty-three holes were drilled and the last of the holes was "sprung" at least two days before dynamite was placed in them. Fifty-two holes were loaded with 44,000 pounds of 45% dynamite. The charges had been tamped and the fuses set in all. The last hole was being loaded. The entire charge was to be set off by electric current from the Empire Power Plant after five o'clock on the day of the accident. The wires were not strung and the fuses of no two of the holes were joined. Furthermore, the dynamos at Empire were not in service at the time the explosion occurred. It was a clear day and there was no lightning to which the explosion could be ascribed. While the cause of the accident was never definitely determined, it developed later,

when the water in the bottom of the holes was examined chemically, that the water was acid, and that it would attack the cartridges, liberating the nitroglycerin. It was known that a "dobe" blast had been fired just across the Cut from where the explosion occurred, and it was assumed that the accident was due to the detonation of a quantity of free nitroglycerin by the jar of the "dobe" blast. Further investigation showed that the action due to the acidity of the water required approximately twenty-four hours for the release of the nitroglycerin, and the holes had been loading for several days. As a consequence, instructions were issued that no loading operations would be undertaken in any area that could not be completed and fired the same day.

When the loading gangs took charge of areas that had been drilled, the holes were "sprung"—several sticks of dynamite were placed at the bottom, the quantity depending upon the character of the material, a light tamping put in, and this small charge exploded with a magneto electric machine, thereby creating a chamber at the bottom of the hole. The loading followed. The amount of dynamite used varied with the character of the material, the depth and distance apart of the holes, averaging in the earlier stages of the work from 75 to 200 pounds when the holes averaged 20 feet in depth.

When a number of holes were fired even with light charges the vibration in the ground some distance from the Cut was very perceptible. This led to the belief that the slides, which became more extensive and greater in number as the depth of the excavation increased, might in a measure be induced if not produced by the blast destroying the cohesion of the material in the neighboring banks. If this were true, the charges should be reduced, but there was no means of determining. The claim was made that "dobe" blasting was more disastrous to the banks than the deep blasting, but a series of experiments indicated that while the concussion was greater with the former, no earth tremors resulted, as was always the effect of the deep blasts. "Dobe" blasting consisted of placing two or more sticks of dynamite, depending on the size of the rock, on top of the piece to be broken up, covering the dynamite with mud and firing by a tape fuse. The great difficulty was that if the

ground were not broken thoroughly, a number of large pieces remained, some of them too large for the shovel to handle, which necessitated recourse to "dobe" blasting. Such blasts delayed the steam shovel, interfered with track gangs, drills, etc., in the vicinity, thus increasing the cost; the powder men would be held responsible for not shooting properly, with the result that heavier charges would be used the next time. To reduce the charges, therefore, it was decided in January, 1911, to reduce the depth of cuts to the average of twelve feet; also, while the amount was left more or less to the judgment of the powder man in charge, the average was narrowed down to about one pound of dynamite to two or two and one-half cubic yards of material.

The fuses before being placed were tested by a galvanometer, and two fuses were inserted in each hole; after insertion, the galvanometer test was made again. When everything was in satisfactory condition, the fuses were connected in multiple arc with conductors leading from the power plants, and at a given signal the whole area was fired.

The following figures for the month of March, 1912, may be taken as an index of normal drilling and blasting operations in the Cut when the work was at its height: The 202 tripod drills, at work in varying material, made a total penetration of 213,874 linear feet, an average of 41.6 feet per drill each day. The number of drill days was 5142. The 173 well drills in 3176 drill days penetrated 192,604 linear feet, a rate of 51.8 feet per drill day. The average for both kinds of drills was 45.9 linear feet per drill day. Fifteen tripod drills, working exclusively in hard rock, penetrated 11,095 feet in 378 drill days, or 29.4 per drill day. The working day was nine hours.

In blasting, 20,133 holes were exploded in various sorts of material. The aggregate depth of the holes was 345,223 linear feet; the average depth was 17.3 feet. In all, 415,709 pounds of dynamite were exploded, an average of 20.7 pounds per hole. The average efficiency of the blasting during the month, in all kinds of material, was 2.14 cubic yards per pound of explosive.

The steam shovels followed through the blasted area. As already noted, the equipment received by purchase from the

French was replaced as rapidly as new machinery could be purchased and put into condition on the Isthmus for work. The first steam shovels purchased were the largest size procurable, 95 tons, and the first one was placed in operation on November 11, 1904, and the last of the French excavators was discontinued on June 16, 1905. On August 1, 1905, there were 11 steam-shovels at work, but their output was greatly handicapped by the lack of proper transportation facilities. Work in the Cut did not begin on a large scale until the latter part of 1906, or the beginning of 1907, and from that time until the close of the fiscal year 1911, during which year the maximum output was reached, there was a steady increase in the amount of material excavated as new equipment was installed.

The steam shovel equipment purchased for the dry excavation of the canal consisted of:

10 — Bucyrus	45-ton
35 — "	70-ton
32 — "	95-ton
1 — Marion	Model 20
7 — "	Model 60
16 — "	Model 91

and one No. 21, one-man operating Thew, which was purchased for excavating the lateral culverts in the locks on the Pacific side.

The most satisfactory results in Culebra Cut were obtained from the use of the heaviest types; of the two classes of shovels used in the Cut, one was equipped with a dipper of 2½ cubic yards capacity, and the other with a 5-yard dipper, but these dippers seldom dug to their full capacity. The 5-yard dipper was replaced by one of 4-yard capacity when the shovel worked in rock. The greatest number of shovels used in the Cut at any one time was 68, of which 20 were of 70 tons and the balance of the heavier types.

As indicated in the profile (Plate I), the French left the excavated area in rather an irregular condition, and the work of the United States was directed toward removing the irregularities and opening up the entire length of the Cut so as to improve the transportation facilities, and at the same time, towards widening the area to meet the increased width that the

adopted project required. The sea-level canal as projected by the French was to have a bottom width through the Culebra Cut section of 72 feet, while in the same section the canal advocated by the International Board of Engineers contemplated a bottom width of 200 feet, which was increased by Executive Order of October 23, 1908, to 300 feet.

Throughout the entire period of excavation in the dry, the general method or plan adopted by the French of working up grade from either end toward a summit was carried out so as

Fig. 3. Culebra Cut. Completion of Bottom Pioneer Cut. Steam Shovels Meeting at Grade. May 1913.

to maintain drainage, and for a considerable portion of the time that dry excavation was in progress, it gave the additional advantage of providing down grades for loaded trains while the empties were drawn up hill. Drainage was maintained through what were designated "pilot cuts" until the bottom grade of the canal was reached, when the lower portions of the pilot cuts formed drainage ditches through the completed area. The pilot or pioneer cuts were undertaken when the condition of the level on which the shovels were working warranted the deepening

of the Cut to the next lower level. Shovels were then started from either end cutting towards each other and on an up grade varying from 20 to 36 feet to the mile. In these cuts the shovels excavated a width averaging 34 feet at the bottom and 50 feet at the top. A loading track had been laid previously alongside the projected cutting, and Lidgerwood cars were generally used, as this would enable the shovels to cut a bank averaging 12 feet high, while with the side dump cars the depth of the cut was 4 feet less in height. This cut carried the drainage, and trenches were dug connecting it with the upper levels. As the shovel moved forward, a track was laid in the cutting which became the loading track of another shovel which followed in the rear of the first and to its side; this shovel in its turn would cut a trench 12 feet deep when Lidgerwood cars were used, so that a bank averaging 24 feet high resulted on the side of the shovel opposite the loading track. This cut then became the drainage channel. In the same way a track laid in this second cut would form the loading track for another shovel following in the rear and outside of the second. The cuttings made by these shovels averaged about 26½ feet in width and were designated "widening cuts" in contra-distinction to the pilot cuts. In this way the shovels worked in echelon toward the summit, which would be reduced correspondingly when the shovels on the two sides met, and the side banks were 24 to 30 feet in height.

An effort was made to preserve the slopes recommended by the International Board of Consulting Engineers, and the sides were left in a series of steps, but when the Executive Order of 1908 directed the widening of the Cut to a bottom width of 300 feet these steps became obliterated more or less throughout the greater portion of the Cut, as it became necessary to widen out the upper reaches in order to secure the new width required. The reference of the finished bottom of the Cut was 40 feet above mean tide, but to allow for irregularities the excavation was made to 38 and the high points knocked off so as to leave nothing which projected above 40.

The shovels made records on the Isthmus never before anticipated; the maximum for all shovels at work in the Cut was made in March, 1909, when 68 shovels worked 27 days of eight

hours each, and excavated a total of 2,029,435 cubic yards, an average of 29,844.63 cubic yards per shovel. The 68 shovels had a total average efficiency of 56.93 shovel days. The highest monthly record for one shovel was made in March, 1910, by a 95-ton Bucyrus, which worked 26 days of eight hours each and excavated a total of 70,290 cubic yards. The highest daily record was also made by a 95-ton Bucyrus which, on March 22, 1910, in eight hours' work, excavated 4465 cubic yards.

To secure such results, the shovels were worked to the limit of their capacity, and certain weaknesses developed which were corrected in the shops on the Isthmus. The principal improvements were in the booms and circles, which were heavily reinforced; the shipper shaft pinions, which were replaced by pinions of manganese steel; an additional lug on the base castings, which otherwise worked loose; and in strengthening the lips and teeth of the dippers by the use of manganese steel. To keep the shovels in good condition, a night repair gang was organized, provided with a working car containing a forge, a drill, a shaper, and a lathe, all driven by compressed air taken from the air main at whatever point the car was in service. In addition, there was comprised in the equipment of the car pneumatic drills and hammers that could be handled by one man, the usual tools of the various trades represented in the repair gang, and a 30-ton locomotive crane. A steamshovel was not taken to the shops unless it required general overhauling; all minor repairs, and even large repairs, such as replacing main engine frames, dipper sticks, and boilers, were performed in the field, at night, without interruption to the operation of the shovel.

Coaling of the shovels was done at night by two trains, each made up of a locomotive and eight 20-yard cars, which entered the Cut at different points. A car with two negro laborers was spotted at each shovel, an effort being made to so place it that the coal could be handled directly by shoveling from the car to the bin of the steam shovel. If this were not possible, a plank was placed from the car to the shovel and the coal was transported by means of a wheelbarrow. After the shovel had been supplied with the coal required, usually 40 or 50 tons, the car was shifted to another shovel; and so the work was continued

until all the shovels, from the lowest level to the highest, had been coaled.

Three classes of cars were used for the bulk of the work. The wooden flat cars with one high side and the other side open, so constructed that they could be emptied by an unloading plow, had a rated capacity of 19 cubic yards. Twenty of these cars were ordinarily hauled in a train, and the spoil on a train would be, therefore, about 380 cubic yards. The next largest cars were

Fig. 4. Culebra Cut, Culebra. Steam Shovel Loading Rock. March 1911.

the Western and Oliver air dumps, which had a rated capacity of 18 and 19 cubic yards, but were rated on the canal at 17 cubic yards; these were used almost exclusively in hauling rock from Culebra Cut to the Gatun Dam. Twenty-seven of these cars composed a train, and the amount of spoil on each train was, therefore, about 459 cubic yards. The small Western and Oliver dump cars, known as the "12-yard dumps", were rated at 10-yards capacity each, and 35 of these ordinarily composed a train, the amount of spoil in each train being, therefore, 350 cubic yards.

The rated capacity of the dump cars was based upon cross-section measurements covering a long period. Careful data were kept of the excavation by cars, and each month this was compared with the excavation as determined by cross-section measurement. The difference between the two methods of measurement was never great.

The time taken for loading each car varied according to the material in which a shovel was working, and to the innumerable small delays incident to the excavation and transportation of the spoil. An illustration is the work done by 20 steamshovels in the Culebra Cut section on November 11, 1910, when 30,077 cubic yards of rock and earth, an average of 1503 cubic yards per shovel for the eight-hour working day, were excavated. The shovels were under steam 160 hours, were actually digging 109 hours, were waiting for cars 38 hours and 40 minutes, and were delayed the remainder of the time by mining, cleaning track, repairs to shovels, track repairing, and moving the shovels forward. With all conditions favorable,

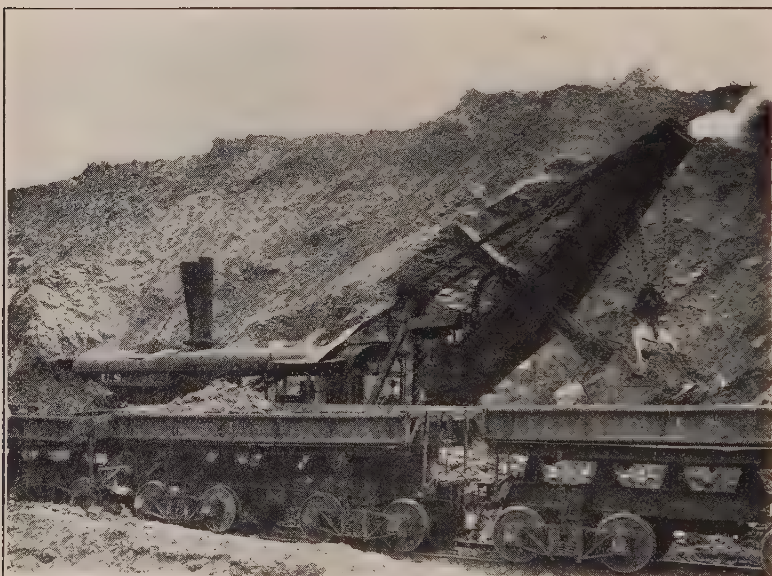


Fig. 5. Steam Shovel Loading Oliver Dump Cars, East Bank of Cut North of Gold Hill. March 1914.

it was found that a shovel could complete a digging operation in one minute, and thus load a 19-yard car in about eight minutes.

From the beginning it was recognized that the working efficiency of the steamshovels depended primarily upon the means of disposing of the spoil; to "make the dirt fly" meant to move it out of the prism. The shovel engineers' detailed reports of delays classify them as mining, cleaning track, repairs, switching, derailments, moving up, cutting out, waiting for steam, and waiting for cars. In an aggregate of reports covering any considerable length of time on a large job, "waiting for cars" is chargeable with the maximum time loss, unless transportation is markedly expeditious.

In the 8½ mile length of Culebra Cut, the number of shovels at work during the active construction period averaged about 37, and, though this number was diminished by perhaps six as the area of the excavation drew toward the summit of the continental divide, the concentration of work within a mile and a half of channel intensified the problems of transportation. In the section just north of Gold Hill were seven parallel tracks, on the levels of excavation, which were in constant use. Slides frequently put all but one or two out of service, so that the removal of tracks and the laying of new ones averaged about a mile a day. The disposal of spoil, except from the half-dozen shovels engaged in terracing at the tops of slides, was made at dumps from one to twenty-three miles beyond the ends of the Cut, to which must be added the distance of the shovels from the ends of the Cut. Under these conditions, the transportation involved unusually acute "railroading".

The operation of trains was controlled by a superintendent of transportation and a chief dispatcher, from their joint office in the Division Engineer's building at Empire. Their work for the day began the evening before, when, from reports by telephone from the yardmasters in the Culebra and Empire construction districts, as to the position of the trains at the close of the day's work, they ordered bulletins posted at the roundhouses at Las Cascadas and Pedro Miguel covering the disposition of crews and locomotives for the next morning. As

the locomotives came in from the day's work, the crews on the extra list learned from the assignment board at which roundhouse to report the next morning, which they did by early labor train. From these same orders the hostling crews at the roundhouses distributed the locomotives on numbered tracks which indicated their destination. A crew boarding an engine at Pedro Miguel roundhouse knew from the number of the track upon which it was placed whether it was to go direct to the Cut by way of the Paraiso incline, or to make its way to the dumps north of the Miraflores tunnel, or to Balboa; at Las Cascadas, the arrangement showed which locomotives were to go into the Cut from the west side down the incline at bridge No. 50½, which were to cross the dike at Matachin and go down the east side, and which were to proceed across the Chagres River bridge to the dumps along the relocation of the Panama Railroad.

As the locomotives entering the Cut passed the tower of the district yardmaster, he directed their passage to the trains of cars by order cards handed to the conductors. The first engine went to the farthest train, and the others, in order, so that there was no congestion due to backing in or crossing over. Throughout the day the district yardmasters directed the passage of the loaded trains to the various dumps, by telephone reports from dump yardmasters on their readiness to receive spoil; and on the return of the empty trains, distributed them to the shovels. From half a dozen small towers distributed along the line of excavation, tower-tenders kept the yardmasters informed of the progress of loading in their vicinity. The yardmasters ordered the right-of-way for loaded trains, and reported their passage out of the district to the dispatcher, who handled the trains to the dumps. On their way, most of them passed on to the main line of the Panama Railroad. The dispatcher's office had direct telegraphic connection with the lines of the railroad, and was informed as each train entered and left a block. The train crew took its orders from the semaphores.

At each set of dumps was a yardmaster who reported to the dispatcher the arrival and departure of trains, and his

readiness for spoil. He also ordered the distribution of the loaded trains to the several dumping tracks, as well as the movements of the Lidgerwood unloaders and the spreaders and trackshifters. Prior to June 30, 1907, loaded trains were hauled from the Cut to yards which had been constructed at Whitehouse, near Las Cascadas, and Pedro Miguel, where the engines would pick up an empty train that had been returned to the yard from the dumps, and go back to the Cut. The loaded train would be taken to the dumps by the engine bringing the empty from the dumps. The trains were controlled and directed by the superintendent's office as outlined. Subsequent to this date, the use of the yards for this purpose was abandoned, though empty and loaded trains were stored in the yards when, at the noon hour or at the close of the day, time did not permit reaching the Cut or the dumps.

The construction tracks laid within the limits of Culebra Cut on July 1, 1911, totaled 76.18 miles, and these combined with the construction tracks within the division limits, including the dumps, but exclusive of the Panama Railroad over which most of the spoil was carried, totaled 209.16 miles in length. Two through main lines were maintained in the Cut, and in order to facilitate the movements of trains all tracks were ballasted. For this purpose a crusher plant, consisting of one No. 8 Gates rock crusher, one Chandler & Taylor engine, with boilers, two Lidgerwood hoisting engines, with the necessary shafting, pulleys, etc., for the equipment, was established at Bas Obispo; but this was moved in October, 1908, when it became necessary to widen the prism to the west, and reerected on the 95-foot level on the east side. Rock was taken from the spoil of the Cut, dumped near the plant, and handled to the crushers by Decauville cars. This method of procuring ballast was continued until December, 1909, when gravel was substituted for crushed stone. Gravel was secured from a deposit made by the Chagres River in the prism which had been excavated on the other side of the river from the Cut.

The locomotives which replaced most of those acquired from the French and which were purchased for the entire work, exclusive of the Panama Railroad, consisted of:

100—Built by American Locomotive Company, Cooke Works (Class 200), mogul type; cylinders 19 in. x 24 in.; driving wheels 54 in. diameter; weight on drivers, 108,500 pounds; total weight of engine, 125,500 pounds; total weight of engine and tender, 222,500 pounds; tractive power, 23,980 pounds at 10 miles an hour; hauling capacity, 3,317 tons on level.

40—Built by Baldwin Locomotive Works (Class 300), mogul type; cylinders 19 in. x 24 in.; driving wheels 54 in. diameter; weight on drivers, 106,810 pounds; total weight of engine, 122,310 pounds; total weight of engine and tender, 210,310; tractive effort, 23,960 pounds at 10 miles an hour; hauling capacity, 3,318 tons on level.

20—Built by American Locomotive Company, Brooks Works (Class 600), mogul type; cylinders 20 in. x 26 in.; driving wheels 63 in. diameter; weight on drivers, 127,500 pounds; total weight of engine, 147,500 pounds; total weight of engine and tender, 234,500 pounds; tractive effort, 24,690 pounds at 10 miles an hour; hauling capacity, 3,447 tons on level.

A number of French engines were continued in service for the entire period of the work. The engines were hostled and provisions made for minor repairs the night following the close of the day's work. Heavier repairs were made at the shops established at Gorgona, Empire, and Paraiso, but the last was closed in the fall of 1908, and ultimately all engine repairs of magnitude were made at the Gorgona Shops; when these were moved in anticipation of being flooded out by raising the level of the lake, they were made at the Balboa Shops.

The cars purchased for handling spoil, coal and ballast, and utilized on the entire canal work, consisted of:

1800—Wooden flats,	weight	36,500	pounds,	capacity	80,000 pounds.
1800—Steel dumps,	"	32,500	"	"	12 cubic yards.
600—Steel dumps,	"	32,500	"	"	12 " "
300—Steel dumps,	"	42,500	"	"	18 " "
300—Steel dumps,	"	44,000	"	"	19 " "

12—Goodwin automatic steel dumps, weight, 55,500 pounds, capacity, 40 yards.

12—Ingoldsby patent automatic wooden center dumps, weight, 43,000 pounds, capacity, 40 yards.

In addition, French dump cars were used for various parts of the work until July 1, 1911, when they were entirely withdrawn from the service.

The trains carried the spoil to dumps, located at various points on the Isthmus. At first, suitable localities in the immediate vicinity of the Cut were utilized, but as these were filled up, new ones at greater distances were selected. Though much of the spoil was utilized in useful work, the larger portion was wasted. However, a large part which when disposed of was considered as wasted was subsequently found to be useful, notably the dump north of Gamboa, where a small settlement has sprung up in connection with the Chagres River gravel plant, and the Balboa dumps, where there is building a military post, wireless station for shipping in the Pacific, and where the quarantine station is established. When the construction of the Gatun Dam was begun it was decided to utilize the rock removed from the vicinity of Bas Obispo for the toes and faces, but in July, 1909, the run of the Cut was used to form the embankments confining the hydraulic fill.

The following table shows the distribution of the spoil:

Name of Dump.	Quantity in cubic yards.
Gatun	5,419,741
Bohio	177,928
Chagrecito	147,718
Tabernilla	16,099,027
San Pablo	2,210,425
Caimito	1,701,414
Mamei	967,287
Juan Grande	1,275,642
Gorgona	778,612
Matachin	1,823,006
Incline No. 1	9,229
Santa Cruz	997,582
Point No. 3	18,177
Gamboa	184,792
Gamboa Dike	37,080
Chagres	434,086
Mandingo Dike	5,460
Bas Obispo	338,802
Camacho Dike	920
Bas Obispo Dike	5,174
Tunnel diversion	61,890
Obispo diversion	1,201,465
Sardinilla	4,054

Name of Dump.	Quantity in cubic yards.
Haut Obispo	35,525
Bridge No. 53	314,127
Las Cascadas	55,254
Buena Vista	74,045
White House	101,806
White Yard—Camacho diversion	32,756
Cunette	152,215
Empire	82,222
Cerro	176,998
Cableway	1,356
Culebra	1,653,103
Gold Hill and Lirio	2,144,758
Rio Grande	678,854
Cucaracha	48,438
Cartagenita	262,369
Paraiso	74,885
Pedro Miguel townsite	16,318
Pedro Miguel	863,751
Double-track south tunnel	8,201
Miraflores	14,603,053
Miraflores north incline	15,545
Corozal	607,851
Power-house fill	84,760
Sosa	667,493
Balboa	21,777,489
Bas Obispo Crusher	184,234
Naos Island Breakwater	1,435,173
Panama Railroad:	
Relocation, Caimito to Gamboa	12,394,572
Relocation, Paraiso to Corozal	972,783
Relocation dumps	6,159,274
East Mamei	180,432
Culebra Swamp	713,290
Point No. 4	611,240
Pacific Division	183,489
Balboa Y fill	791,560
Sosa Hill fill	17,545
Ancon-Sosa fill	1,064,455
Ancon-Diablo fill	25,998
Cristobal Mole	231,956
Panama R. R. relocation for rip-rapping	348,514
Miscellaneous	5,416,349
Total	109,163,547

The Lidgerwood cars were wooden flat cars with one high side and the other side open; most of the spoil from Culebra Cut was hauled on cars of this type, which were unloaded by means of plows drawn along the train by 60-ton-pull Lidgerwood unloaders, of which 40 were purchased and used. These unloaders were mounted on flat cars, and each consisted of a drum 54 in. in diameter, around which the cable was wound, operated by an engine at either end with 12-in. cylinders and

Fig. 6. Lidgerwood Unloader, Tabernilla Dumps. 14% Grade.

12-in. stroke. These engines had steam-pipe connection to the steam drum of the locomotive to which the car containing the unloader was coupled.

The high side of the Lidgerwood flat car, permitting a heavier load on that side of the car than on the other, caused an unequal distribution of weight, and this was overcome to some extent by extending the floor 11 inches on the low side, thus throwing the weight of the load nearer the center line of the trucks; this extension also enabled the unloader plows to throw the spoil farther away from the tracks. It was found

early in the use of these cars that the unloading plow was causing a lot of damage to the high sides by running into them when passing from one car to another. The cause of this trouble and expense was eliminated by binding the high sides of the car with an iron ferrule, known as a "bull nose", which by presenting a beveled edge to the plow steered it into position as it passed from car to car. These cars were also provided with a sheet-steel apron so fastened to the end of one car that it could lap over the coupling mechanism and thus make the train continuous for plowing. The aprons were so set that the plows frequently tore them off; there is a record of 130 aprons being torn from the cars in one day. The means of fastening these aprons was changed so that this damage seldom occurred thereafter. In handling material in slides, or at other points, where it was necessary to uncouple cars from a train and back them alongside the shovels, the steel aprons that bridged the intervals between the cars were thrown back, in order that the couplings might be parted. In loading, these aprons were frequently covered with a ton or so of spoil, and when it became necessary to throw them back into position, so that the plow could pass over them, considerable labor was required to take off the spoil. This extra work was obviated by an apron thrower, which consisted of a short chain with a hook on one end and a cable grip on the other. The hook was placed under the apron and the grip fixed to the moving unloader cable, and thus the apron was returned to its correct position in advance of the plow.

Trouble was also experienced in the first days of the heavy trains by the coupling breaking and the trains separating. A bridle was devised which overcame this difficulty, and held the cars together in case the automatic coupler parted from any cause, such as a worn knuckle, worn or broken lock, broken knuckle tongue, broken jaw, or even in case a drawbar carrier came down. Each train crew was supplied with two of these bridles for emergencies, and 1200 of them were made for canal and Panama Railroad service.

When first used on the canal work, the unloader plow was a skeleton with a plate wing. It was weighted down with from

seven to twelve tons of ballast in order to keep it on the bottom of the cars and so prevent it from riding over the spoil. Small pieces of rock were continually working under the bottom and over the top of the plow, and, as there was no way for the debris to escape except by being ground out, constant damage was done to the car floors and trouble was also caused by the debris catching in the aprons. The plow was covered with sheet steel on the top and bottom and thus the small rock was excluded, while, by an adjustment of ballast along the share of the plow three and one-half tons of weight were found sufficient to hold the plow on the floor, entirely overcoming its tendency to rise.

At first it was necessary to spend several minutes in digging out the end of the cable attached to the plow from the spoil along the face. This waste of time was eliminated by forming grommets of worn-out cable and attaching them to the plows where they were always in plain sight, so that the unloading cable could be coupled to the grommet without any additional labor. Time was also wasted at first in attaching the cable to the stretching frame, which consisted of two uprights properly held together and braced spanning the track, and loosening it after it had been stretched over the train. A slip link was placed in the chain which held the cable to the stretching frame, and a blow from an iron rod opened this link, allowing the cable to fall upon the car without the train stopping. In this chain there was placed a soft link with a breaking strain of one and one-half tons, and if anything checked the cable in the process of stretching, thereby placing an unduly heavy strain on it, this link gave way, and saved the cable stretcher from being wrecked.

During the first use of the unloader plow a great deal of difficulty was experienced in securing a cable that would stand the strain, but this was finally overcome by securing a 1½-in. cable made specially to meet the needs. The cost of repairs to unloaders steadily diminished from 1910 onward. This was due to careful supervision while the machines were under repair in the shops, as well as requiring unloader engineers to make all field repairs, and to the system of instruction and super-

vision of unloader engineers as to the proper method of handling the machines. In January, 1910, there were eleven machines in service, and the cost of repairs for that month was $7499.80, while the cost of repairs to eleven machines for the month of December, 1912, was only $3850.32. The demands on these machines were very severe; for instance, in March, 1912, when the work was in full swing, there were unloaded 3217 trains comprising 65,555 cars of spoil.

Fig. 7. Spreader at Work on the Naos Island Breakwater.

Twenty-six spoil spreaders were purchased for use on the dumps. After the first introduction of these machines, fifty-one separate improvements were made to adapt them to our work, and each one added something to efficiency or subtracted from the time spent in operating. This spreader consisted of a car on which was erected a machine with steel wings reaching out 11½ feet from the rails on either side. The spreader was operated by compressed air.

As has been mentioned, most of the material from Culebra Cut was hauled to the dumps in Lidgerwood cars, and they

were the most satisfactory for the work, but they required special equipment for unloading as well as a reasonably straight stretch of track on the dumps. While by means of pulleys they could be unloaded on a slight curve, the results attainable did not warrant, in the case at hand, the time required for the operation. On the other hand, the steel side, or ''Western'' dumps, as they were called, could be unloaded anywhere. The 19-yard cars of this type were equipped with air for dumping, but the length of the train and the available air from the engine permitted the handling of a relatively small number of cars at a time. The smaller cars, and as a rule, the larger ones, were dumped by hand. These cars, loaded more heavily on the side towards which they were to be unloaded, dumped themselves when the holding chains were unslung, but difficulty was found with the others. Experience finally indicated that the easiest way to dump them was by use of a piece of 4-inch pipe, greater in length than the height of the car body above the ties, engaged one end against the ties and the other against the corner of the car; the slight movement of the train raised the body as the pipe straightened up until the car was unbalanced and its load was delivered. As the car body tilted over, the side door attached to hinged levers was raised, giving an opening between which passed the material in the car. It frequently happened that rocks too large to pass the openings were loaded on the cars, and these were broken up small enough to pass through by ''dobe'' blasting them on the cars. Relatively small if any damage resulted to the cars by this method, which saved time, the most important element to be considered.

The main dumps were started from trestles constructed for the purpose, and when filled out as far as the spreader would reach, the track was shifted to one of the edges of the dump. This was done by a track shifter devised on the Isthmus for the work. It consisted of a boom, with suitable tackle, extending from a flat car out over the track in advance of the car, by means of which the track was lifted bodily—ties and rails—from its bed. Another boom equipped with tackle practically horizontal in position, and extending at an angle to the side of the car, was used for pulling the track to one side

or another. For operating the booms, the car was equipped with an engine similar to the ordinary hoisting engine. The trackshifter was improved so that the track could be thrown nine feet from its original position in one operation, instead of only five feet as at first. On one occasion, at Tabernilla dump, 1¼ miles of track were shifted twelve feet from the original position in one hour and fifty minutes. Ten of these track-shifters were made on the Isthmus and used on the work. To

Fig. 8. Trackshifting Machine.

permit this trackshifting, the track had one free end, and was made more flexible by an occasional switch-point in laying the rails.

In widening a dump, the track on the trestle was extended on cribbing, or a pile tail trestle, along which the end of the track was shifted as the main track was moved. The dumping operations were begun at Balboa with a view to filling the swamps for a new railroad yard on the Pacific side, and then to make a coffer dam around the area within which were to be constructed the Pacific locks projected at Sosa Hill. When

this project was abandoned and the site of the locks moved inland, the dump already started was continued. It was also decided to extend a causeway out to Naos Island to deflect the silt-bearing current moving from east to west, and thus reduce the maintenance cost of the dredged channel in the Pacific. As a result, 676 acres of land were reclaimed from the Pacific, which are now used for an artillery garrison, quarantine and wireless stations. On the Miraflores and Balboa dumps a second layer of spoil was added to a portion of the dumps, begun by filling in a trestle constructed on the first or lower dump.

Great difficulty was experienced in constructing the Naos Island breakwater, or causeway. The bottom was soft mud which would be squeezed out by the heavier material dumped on it, and as the load would move with the mud, the single trestle in use was destroyed. Finally, the plan was adopted of driving a double trestle, stoutly braced, extending to Naos Island instead of piecemeal out ahead of the dump, and filling from Naos Island north; then when the trestle went out, there would be a sufficient length remaining to permit the continuance of operations. Finally, rock only was used instead of run of the Cut as at first. Special piles 40 to 75 feet long were used and these were spliced in order to reach solid bottom, which in some instances was 120 feet down. Though the difficulties were not so great with the more stoutly built trestle, it nevertheless gave trouble; it could not be completed before steamshovel operations in the Cut ceased, and it became necessary to borrow rock from Sosa Hill in order to complete the causeway. It is 3.29 miles long and 45 feet wide at the top. Two mounds of mud carrying with them rock that had been dumped from the trestle, were pushed up, one on either side of the causeway and parallel with it, approximately 125 feet on either side. On both sides were also visible some of the piles of the trestle sticking points up, the majority located approximately 100 feet to the west of the breakwater, but several at a maximum distance of 220 feet to the east. In bridging the water gap, 1,979,795 cubic yards of material were used.

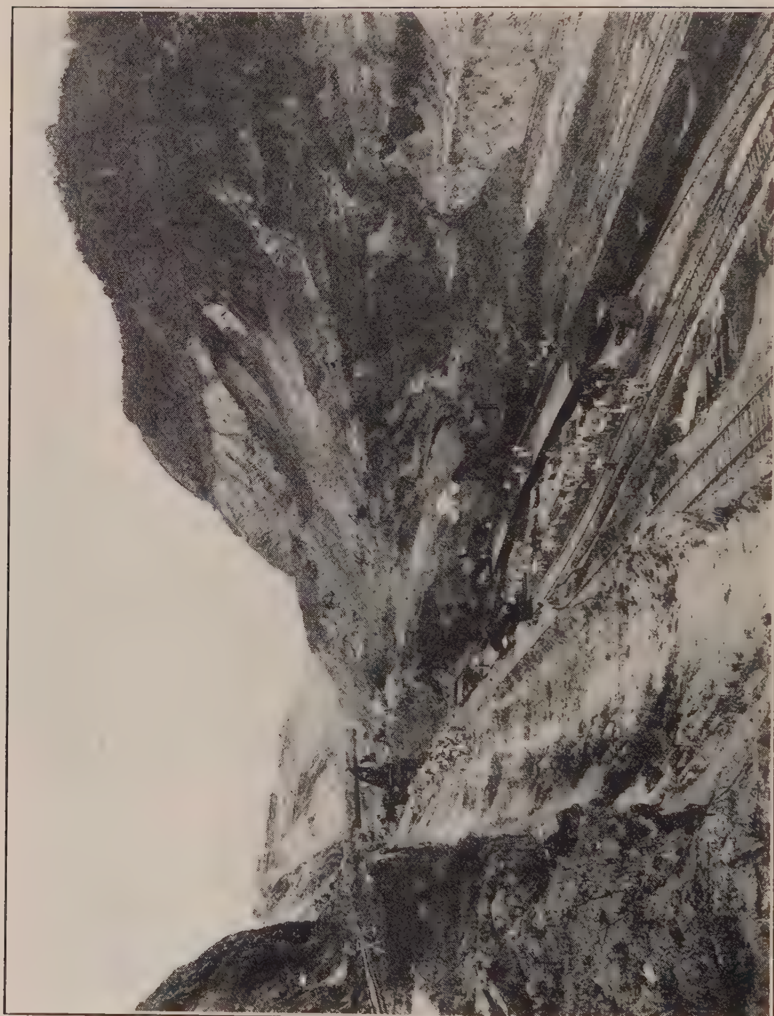


Fig. 9. Culebra Cut, Culebra. Looking North from West Bank south of Contractor's Hill. 2,900,000 cu. yds. in Motion in Cucaracha Slide. February 1913.

The greatest difficulty in excavating Culebra Cut was caused by the slides, an unanticipated source of trouble. It is true that Cucaracha slide existed, beginning in 1884 during the French régime, but this was considered a movement of the surface clay, which could be easily overcome. An examination of the report of the International Board of Engineers leads to this conclusion, as do also the cross-sections adopted by that Board, which show slopes below the rockline of 3 on 2 down

Fig. 10. Culebra Cut. Rock Slide South End of Gold Hill. August 1913.

to the 95-foot level. In the hearings held by the Senate Committee on Interoceanic Canals following the receipt by Congress of the report of this Board, it is asserted by one of the members who had walked the length of Culebra Cut that there would be no slide other than might result in an ordinary clay bank. A geological survey made in 1906 and 1907 tended to verify this expectation, yet serious trouble began in 1907, and the troubles of this nature have continued up to the present time and the slides are still in progress.

As noted, Cucaracha gave trouble to the French, and a

system of drainage was laid out and executed, but this did not relieve the situation. The slide resumed its activity in January, 1905, and a very serious disturbance took place in the fall of 1907, when a large section of the surface of the hill moved entirely across the Cut, overturning two steamshovels, nearly burying one of them; completely covering the main tracks, thereby blocking traffic to the south, and, by stopping drainage, flooding the Cut to the north, preventing some of the other shovels from working. By piping water from the Rio Grande reservoir, the material, consisting of clay, was sluiced, until traffic through the slide was opened and the shovels resumed work.

Cucaracha in its earlier stages was a typical slide, in that it consisted of clay and other material moving on a surface inclined towards the prism, and it was believed that the removal from the prism of the overlying mass, as it moved in, would overcome all further trouble. These hopes were apparently realized when, except for an occasional slight surface sloughing, the slide ceased to be troublesome in the dry season of 1910-11. The geologist also was convinced that the difficulties caused by the slide were practically at an end, and in confirmation of his opinion, the bottom grade of the canal was secured and the widening cuts were progressing towards completion of the section, when, in January, 1913, the rock formation supporting the mass above and back of it, gave way, completely closing the prism, reaching an elevation of 69 on the opposite face of the excavated area. Steamshovels could make but little headway, but by constant digging, traffic was maintained through it on the west side of the canal at elevation 69, until steamshovel operations ceased.

In January, 1907, on the east side opposite the village of Culebra a slide developed, and though it was troublesome, nothing very serious was anticipated. The formation differed materially from that at Cucaracha, and its extent at that time was very small in comparison, yet this, together with the movements along the west bank at Culebra, proved the most difficult and troublesome of them all. In October, 1907, a crack developed fifty or more feet from the face of the bank on the west

side of the canal near the old railroad station at Culebra. Subsequent to the cracking, the ground to the west of it showed perceptible settlement, though the elevation of the portion between the crack and the prism remained unchanged; this settlement was accompanied by a bulging up of the bottom of the canal sufficient to raise the shovel. At the time this occurred the shovel was at elevation 175, and the subsiding portion of the upper bank was at elevation 275. Ultimately the portion

Fig. 11. Culebra Cut, Culebra. Break in East Bank between Stations 1746-1748. General View from West Bank. May 1913.

between the crack and the prism settled down, sliding into the prism. Subsequently new cracks developed farther back, followed by similar settlements and movements into the Cut, involving large masses of material; the same condition developed on the east side. The masses moving into the Cut materially interfered with the work by overturning or blocking tracks, interrupting drainage, and putting shovels out of service. It seemed that whatever material could be removed from the top would be that much to the good. Opposition developed on the ground that an unnecessary amount of material might

have to be handled if this method were adopted; furthermore, an additional amount of trackage would have to be maintained. Following another break on the east side at Culebra, in December, 1910, this method was put into effect and continued until the water was admitted to the Cut in October, 1913, to be resumed subsequently. Similar procedure was followed on the west side and then resorted to at other localities where the conditions warranted. The results were satisfactory in reduc-

Fig. 12. Culebra Cut, Empire. Slide on West Bank below Division Engineer's Office.
The two nearest shovels are on the bottom of the canal; the farther one is 18 ft. above. June 1913.

ing and finally overcoming all movement upward of the bottom of the canal before the water was admitted, at which time the full width and depth had been secured through the length of upwards of 2000 feet along which this rising of the bottom had occurred.

The canal crosses the divide at an angle; Gold Hill is a peak in the divide, and the canal has a slight bend at this point; Cucaracha is a slide from the hills to the southeast of Gold

Hill. On the opposite (northeast) side these hills have steep slopes down to the valley of the Obispo. Material excavated from the upper levels of the east Culebra slide was dumped in the valley of the Obispo well to the east and north, and an opening was left through the embankment carrying the tracks for the passage of the stream. The removal of material from the upper levels of the sliding areas was giving good results; Cucaracha slide was breaking farther up the hill, but the material down the entire face in motion could not support steamshovels and trains, so this plan could not be adopted for this locality. It was therefore decided to remove as much of the material from the top as possible by sluicing, utilizing a portion of the plant purchased for excavating in this way a part of the area below Miraflores locks, which was at the time idle. Consequently, the opening in the embankment was closed, thus storing the flow above the dam that was formed in the upper river valley; the level of the resulting pool was regulated by discharge pipes suitably located. Sluicing operations were begun on the soft material north of Gold Hill, a part of the East Culebra slide, and on the top of Cucaracha slide. The plant installed consisted of:

3—19″ x 30″ x 50″ x 24″ Worthington pumping engines; capacity 7500 cubic feet per minute.
3—500-hp. Babcock & Wilcox boilers.
3—Worthington condensers, 1380 square feet.
3—Duplex pumps 12″ x 20″ x 24″ (for condensers).
2—Alberger booster pumps, 12-in., 2-stage, "V"-type turbine, 3000 gallons per minute at 1500 r.p.m.
2—G. E. Co. induction motors, 350-hp., 1500 r.p.m.
1—Giant monitor for 12-in. pipe.
4—Borren Giant monitors for 12-in. pipe.
4—Borren Giant monitors for 16-in. pipe.
Necessary switchboard, pipe and fittings.

Nozzles 2½ in. to 7 in. in diameter at discharge were used with the monitors, but most of the work was done with 4-in. and 5-in. nozzles. By means of this plant, 1,633,647 cubic yards of material were washed back and deposited in the valley.

In the dry season of 1913-14 an examination of the banks on the east and west sides at Culebra disclosed the development of cracks in some of the benches, and though there

had been a small movement from the east side subsequent to the admission of water, this had been cleaned up by the dredges, and the canal through this section was apparently in good condition. The cracks were suspicious, and to guard against possible contingencies, it was considered wise to resume steam-shovel operations. This was done and continued until July 1, 1914, when all trace of the cracks having been removed, excavation was stopped. There remained the crack on Zion Hill,

Fig. 13. Culebra Cut, Empire. Rock Slides on East Bank of La Pita Point. Nov. 1914.

but this gave no concern, as assurances had been given that the geological formation was such as to preclude any movement. As the last steamshovel was being taken away from the west side, the lowest bench gave way, the material moving into the Cut; the amount was small and easily removed by dredges.

The canal was opened to commerce on August 15, 1914, by which date a channel 150 feet wide and 35 feet deep had been secured through Cucaracha slide, and there was every

hope of maintaining it, as the dredges were removing the material much faster than it came in. On October 15, as work at Cucaracha was drawing to a close, the east bank of the Cut north of Gold Hill for a length of 2100 feet and extending back 1000 feet from the center line of the channel, settled down, and about 725,000 cubic yards of rock and earth were squeezed out and into the canal prism. When the movement occurred there were 45 feet of water; an hour later there were only nine

Fig. 14. Culebra Cut from Contractor's Hill, looking North. April 1910.

inches in some parts. Movements subsequently took place on the west side, and this section continues to be the troublesome one.

In May, 1910, a portion of the rock bluff at La Pita Point was to all intents and purposes pushed out and settled down, turning the waters of the Obispo diversion into the canal, necessitating the construction of a new channel, as already noted. Another break of a similar kind occurred in the same vicinity, but to the north of La Pita Point, on August 20, 1912.

There were 22 slides at different points along the line,

involving the removal of amounts of material varying from 3300 cubic yards in the slide at Pedro Miguel to over 9,000,000 cubic yards from the West Culebra slide, before the admission of water in October, 1913. The total amount removed by steam-shovels because of the slides was 25,206,100 cubic yards, or 25.32 per cent of the total removed in the dry from the Cut.

Various means were adopted to reduce or prevent the slides, but without success. A geologist was employed with

Fig. 15. Culebra Cut, Culebra. Looking South from West Bank. August 1914.

the hope that material assistance would be secured, but the situation was an entirely novel one to him, as it was to the engineers. Though the method of removing weight from the upper levels had been adopted at the Culebra slides, this was applied to other localities where the geologist thought the formation warranted it. Piles were driven with the hope that by catching firmly in solid ground they might assist in holding the upper portions, but in no case were they of any avail. Rock dumped on the surface had proved efficacious elsewhere, and this was tried with some success, but only in the case of one of the

small slides. Drainage has been tried and undoubtedly assists. The great difficulty is that there is, so far as known, no means of determining where the slides are liable to occur, and the first intimation of anything wrong is the slide or break itself. With the geological formation changing so frequently and suddenly, both in the direction of the Cut and up and down, there is no possibility of any uniformity in slopes. No uniformity of slopes could be maintained, as will appear from Plate II, which

Fig. 16. Culebra Cut, Culebra. Looking South from West Bank, showing Condition of Both Banks. February 1915.

shows the slopes at various localities, and at the Culebra slides these slopes are not yet the final ones.

Dry excavation was not confined to Culebra Cut, but extended to various localities between the Atlantic and Pacific. The adoption of the 85-foot level project materially reduced the amount of excavation, but where steamshovels were used the methods introduced and carried out in Culebra Cut were applied to other localities.

The Chagres River between Gamboa and Gatun crossed

the line of the canal twenty-three times, and therefore the canal was cut through certain peninsulas, which in the reports were designated by numbers. Floods in the Chagres materially interfered with progress in this portion of the canal. While most of the work in this section was done by day's labor, some of it was done by contract. This method was first adopted for an isolated portion between miles 17-19, where heavy equipment could not be used advantageously, and to avoid the necessity of establishing camps, commissaries and messes. Task work was

Fig. 17. The Cut at Caimito During Flood of June 15, 1909.

adopted and natives living in the vicinity were employed. The contractor for some excavation at Bohio used a sluicing plant, washing the larger part of the material into the Chagres River. The contractor for the portion between miles 15-20 failed to complete. There is nothing of special interest connected with the excavation of this portion of the canal not covered by similar features of the digging of Culebra Cut.

Point 1, through the peninsula directly across the Chagres River from Gamboa, formed another channel for the river, and

in November, 1909, the flood which followed its completion caused a heavy deposit of gravel, which was removed the following dry season by a crane equipped with an orange-peel bucket, and used or stored for ballast and for some concrete work. The following wet season added another deposit, which was excavated and used or stored, a steamshovel being substituted for the crane.

The dry excavation in the Chagres River section was completed during the fiscal year ending June 30, 1912, which permitted raising the level of the lake to elevation 50 above sea level. Starting with the lake at 50 on July 1, 1913, under conditions of average rainfall the Gamboa dike would exclude water from the Cut until about the middle or latter part of October, so it was concluded to make preparations for admitting water to the Cut and blowing up the dike on October 10, 1913, subsequently removing what material remained by dredges. Steamshovel operations in Culebra Cut were permanently suspended on September 10, 1913, and all construction material and equipment were removed prior to turning in the water.

To obviate the damage that might be created by the onrush of water into the Cut, water was admitted on October 1, 1913, through the 24-inch pipes that had been laid through the dike, and when the dike was blown up, the difference in level between the water north and south of the dike was six feet. Only part of the dike was destroyed on October 10, the rest of it being demolished piecemeal. The holes were drilled from 20 to 35 feet in depth, and the total number in the dike was 1277. Of these, 419 were loaded with 16,300 pounds of 60% dynamite and exploded about two o'clock P. M., October 10th, by President Wilson at Washington. Cucaracha slide was a complete barrier to the water; though a small channel was dug through part of it, the material would not wash; explosives seemed no more effective, and it took fourteen days to get the water by it so as to secure the same water level on the two sides of it.

The channel through Mindi Hills was excavated by steamshovels in the dry. The work was begun in July, 1907, and completed February 24, 1912. The original elevation over the

area removed for the canal prism averaged 20 above sea level on the center line, and the highest point within the limits of the prism was at elevation 60, the top of the knoll on the west side. It was proposed to excavate the area in the dry to sea level, blast what remained and complete by dredging, on the ground that the seamy character of the rock in the hills and the portion bordering the French canal which was to the north of the area would admit too much water to continue dry excavation much, if any, below sea level. This prediction as to seepage did not prove true. The excavation was carried to 42 feet below mean sea level, the water of the French canal being excluded by a dike which was left for the purpose, and the pit kept dry by pumps. The dike was 20 feet wide at the top (elevation 8), with an interior slope of 2½ on 1 and an exterior slope of 1 on 4, which gave a thickness of 55 feet at sea level. The pumping equipment installed consisted of three 8-inch centrifugal pumps and one 15-inch centrifugal pump; the total capacity of these pumps was 12,000 gallons per minute. As the flood of 1909 in the Chagres River had access to the French canal, the pit was flooded, which suspended operations on November 20, 1909, and they were not resumed until February, 1911, when the water was pumped out; the sediment that had been deposited and clay washed in, were sluiced out, and the excavation completed.

The excavation for the locks at Gatun, Pedro Miguel, and Miraflores offered no novel features, and was performed by steamshovels loading into Western dumps. The channel between Miraflores locks and deep water in the Pacific was excavated by dredges, steamshovels, and by sluicing. That done by steamshovels was protected by two dikes; the outer one was subsequently removed when an inner one was constructed, thereby extending dredging and reducing the steamshovel work, after the area between the two had been stripped of material that could be sluiced, and broken up by blasting for the dredges.

The accompanying table gives by localities the amount of material removed, its classification into earth and rock, and the methods employed.

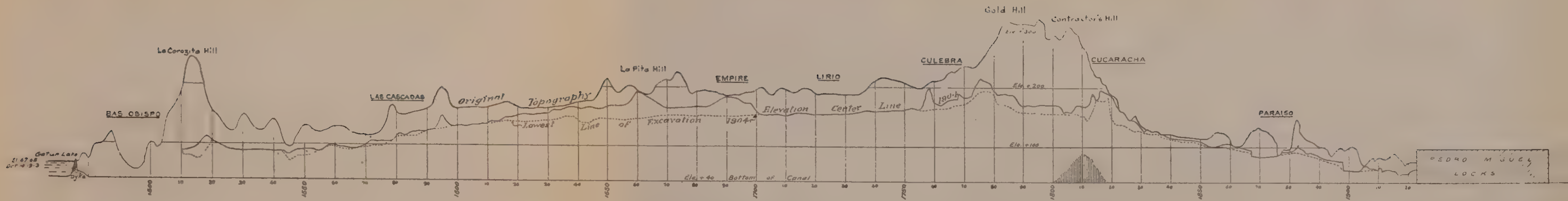
Total Dry Excavation by Americans up to April 1, 1915.

Location.	Prism. Earth.	Prism. Rock.	Prism. Total.	Outside Prism. Earth.	Outside Prism. Rock.	Outside Prism. Total.	Grand Totals.
Atlantic Section:							
Cristobal Coaling Plant—Orange Peel and Hand				12,733	1,188	13,921	
Mindi:							
By steam shovels	509,420	1,672,578	2,181,998				
Hydraulic	29,605		29,605				
North — Between Gatun Locks and Dyke:							
By steam shovels	69,515	72,163	141,678				
Hydraulic	3,391		3,391				
Crane, Hand and Scraper	2,827		2,827				
Gatun Locks:							
By steam shovels	1,750,589	3,016,395	4,766,984				
Gatun Spillway—By steam shovels				1,007,293	583,221	1,590,514	
Permanent Power Plants—By steam shovels				96,142	7,325	103,467	
Las Guachas Creek Saddle—By Hand and Scraper				4,117		*4,117	8,838,502
Cano Saddle—Contract with Hebard & Lombard—By Hand				72,105		†72,105	72,105
Chagres Section: (Contracts)							
Contract with Hebard & Alberts to excavate at Barbacos Bridge and between Miles 17-19:							
By hand	120,959	49,849	170,808				
Contract with M. B. De Putron to excavate in the vicinity of Gorgona:							
By hand	3,602		3,602				

*Not included under "work" excavation.
†Not included under "work" excavation.

Location.	Prism. Earth.	Prism. Rock.	Prism. Total.	Outside Prism. Earth.	Outside Prism. Rock.	Outside Prism. Total.	Grand Totals.
Contract with E. C. McFarland to excavate at Tabernilla—M-22-2300 to M-23-3600 and at Bohio—M-17-2450 to M-17-4450:							
Hydraulic	104,292	8,856	113,148				
By hand	16,208	77,776	93,984				
Contract with Llwellyn Swain and B. B. Duncan. Mile 28-0950 to M-28-2400, east side: (Pt. 4B)							
By steam shovel	16,914		16,914				
Hydraulic	48,435	26,656	75,091				
By hand	16,987		16,987				
Contract with B. B. Duncan:							
By hand—Mile 15	47		47				
By hand—Mile 20	350		350				490,931
Chagres Section: (By Government)							
Point 1	‡	‡	1,590,101				
Point 2			1,452,648				
Point 3			855,443				
Point 4			839,108				
Point 4-B (Remainder of Swain Contract)			12,196				
Point 5			462,065				
Point 6			158,979				
East Mamei			606,528				
Mamei			382,757				
San Pablo			1,531,099				
Camito			2,268,379				
Cano River			707,031				

‡Detailed earth and rock amounts, by points, were not compiled. See totals for entire district.



SECTIONAL ELEVATION
ON CENTER LINE OF CANAL

PLAN OF CULEBRA CUT
ON OCTOBER 10th 1913.

Shows Active Slides.

Non-Active Slides

Plate I.

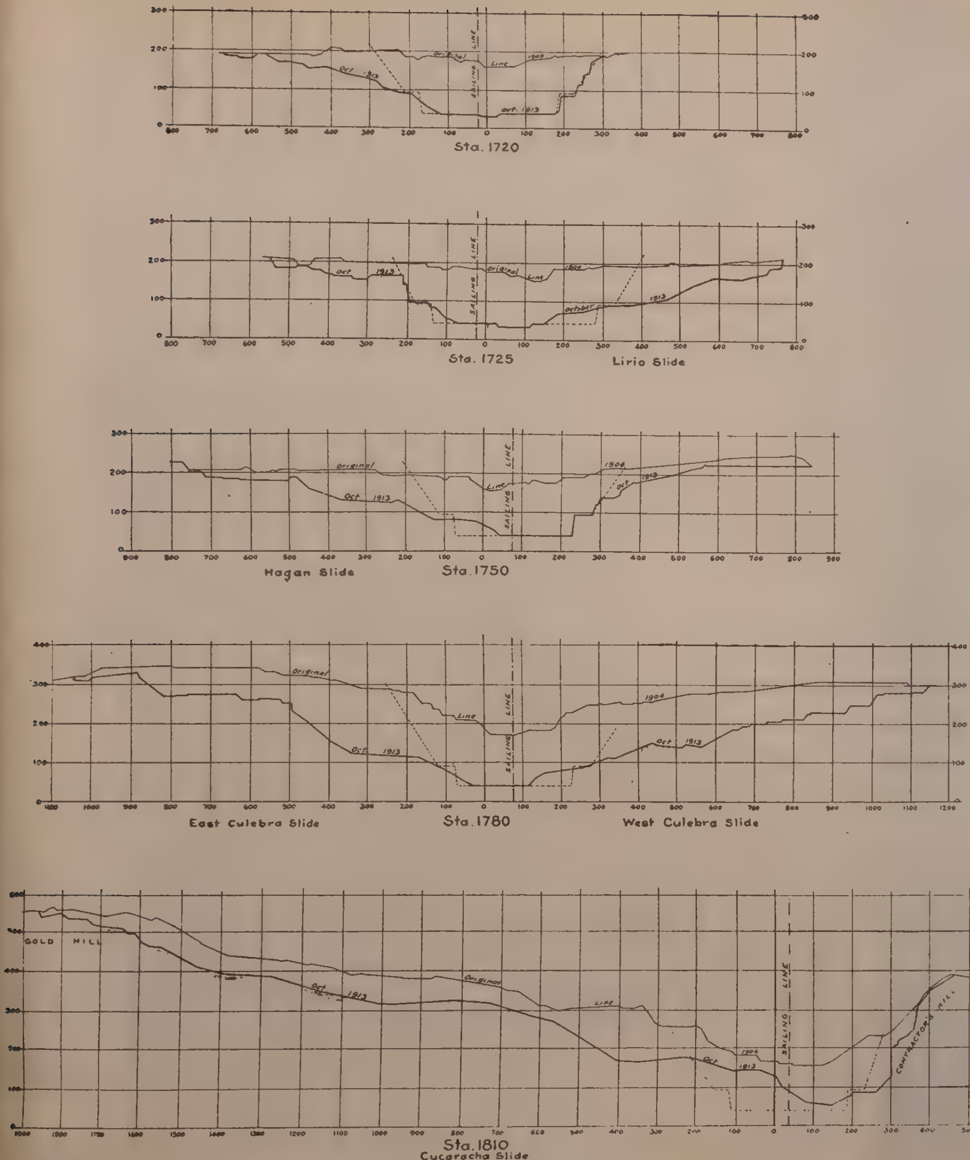


Plate II. Cross Sections of Culebra Cut.

Location.	Prism. Earth.	Prism. Rock.	Prism. Total.	Outside Prism. Earth.	Outside Prism. Rock.	Outside Prism. Total.	Grand Totals.
Tabernilla			606,249				
Buena Vista			153,246				
Bohio and vicinity (By hand)			184,148				
Bohio—Rock by steam shovel			40,919				
Gatun and vicinity (PRR embankment, etc.)			39,918				
Total earth and rock, Chagres Sect., by Govt.	9,209,006	2,681,808					11,890,814
Culebra Section:							
Gamboa to Pedro Miguel:							
By steam shovels (inc. some clam shell)	20,307,618	76,136,859	96,444,477				
Gold Hill Hydraulic	866,207	799,994	1,666,201				
Obispo Diversion—East side Canal:							
By steam shovels and scraper				854,325	468,570	1,322,895	
Hydraulic				10,478		10,478	
Camacho Diversion—West side Canal:							
By steam shovels				64,843	20,814	85,657	
Old Culebra Dump Drain—West side:							
By steam shovel				27,300		27,300	99,557,008
Pacific Section: Pedro Miguel Locks:							
By steam shovels	412,622	877,189	1,289,811	17,049	517	17,566	
By hand	7,671		7,671	6,015		6,015	
Miraflores Lake:							
By steam shovels	761,089	41,730	802,819				
Miraflores Locks:							
By steam shovels	902,007	1,308,614	2,210,621				
Hydraulic	332,703		332,703				
By hand	1,469		1,469				
Miraflores Spillway and Dam:							
By steam shovels				110,734	165,168	275,902	
Hydraulic				9,896		9,896	

Location.	Prism. Earth.	Prism. Rock.	Prism. Total.	Outside Prism. Earth.	Outside Prism. Rock.	Outside Prism. Total.	Grand Totals.
Permanent Power Plants, etc.:							
By steam shovels				16,398	12,477	28,875	
Rio Grande Diversion:							
By steam shovels				34,743	6,420	§41,163	
Rio Cocoli Diversion:							
By steam shovel				4,718	6,128	10,846	
By hand				547		547	
Channel south of Miraflores Locks:							
By steam shovels	1,389,955	2,759,263	4,149,218				
Hydraulic	1,549,904		1,549,904				
Pacific Terminals:							
By steam shovels and hand				944,943	1,184,269	2,129,212	12,864,238
Totals	38,433,392	89,529,730	127,963,122	3,294,379	2,456,097	5,750,476	133,713,598

Recapitulation.

By steam shovels	129,353,307
Hydraulic	3,790,417
By hand	569,874
Total	133,713,598
Total Earth	41,727,771
Total Rock	91,985,827
Total	133,713,598

By Government	133,150,562
By Contract	563,036
Total	133,713,598
By Hand (Contract)	357,883
Hydraulic "	188,239
Steam Shovel "	16,914
Total	563,036

.0042% of total amount by contract.

§Diversion excavation in Pacific Section charged to "Plant" not included in this amount.

Paper No. 11

CONSTRUCTION OF GATUN LOCKS, DAM AND SPILLWAY.

By

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The project recommended by the minority of the International Board of Engineers, and adopted by Congress, contemplated a duplicate flight of three locks at Gatun, with an aggregate lift of 85 feet, and a dam across the Chagres Valley at the same place, with regulating works to control the lake level within specified limits. Plate I shows in plan the Gatun Locks, Dam and Spillway as built.

An approximate location of the above structures was made in the report of the Board referred to in the preceding paragraph, but time did not permit an exhaustive examination of the material underlying them. One of the first duties of the Construction Division at the Atlantic end of the Canal was, therefore, to make a complete investigation of the material available for foundations, both for the locks and the dam. This was done by digging test pits and making a well-distributed set of borings, using both the wash rig and the diamond-drill outfit. The object of the borings in the proposed location of the locks was:

(1) To determine the elevation of material that would safely bear the contemplated loads.

(2) The character of such material, especially whether it was sufficiently porous or creviced, or both, to transmit pressure from the lake.

(3) To determine whether or not any material on which any part of the Gatun locks would rest could erode under any reasonable assumption.

The borings at the lock site were extended to a depth of about 50 feet below the foundation level for the purpose of determining definitely the character of the underlying material and the thickness of the various strata under the lock foundations. On Plate II is shown the material underlying each lock wall for the entire flight. The material classified as ''argillaceous sandstone'' has since been denominated by the geologists as indurated clay. That classified as ''conglomerate'' proved to be a conglomerate rock suitable for foundation; this would not core with diamond drill. When the drillers reached the stratum marked ''soft sandstone'', they reported ''black sand''; the material would not core. In order to proceed with the drilling, it was necessary to chop this material, and it was washed up as sand. Water always rose in the drill holes after encountering this stratum, and its persistence led to extensive tests with a view of ascertaining its water-bearing capacity.

A test pit was finally dug into this material outside the lock pit, shown as Test Pit No. 7, on Plate III. The black sand proved to be a soft sandstone capable of bearing any expected load. The effect on the ground-water level in the surrounding holes of unwatering this test pit is shown on this plate. The water level in the drill holes answered quickly to the pumping. From a study of all the experiments, the conclusion was drawn that the passage of water from the holes to the test pit was through small crevices in the rock, rather than generally through the material, and that since the crevices were probably produced by earthquakes, their depths could not be determined.

This state of facts was unknown before, and it led to the design of a floor for the Gatun locks, for about 600 feet at the south end, that would stand the full lake load, if it received it. The soft sandstone under this part of the foundation was mixed with tufa, was creviced, and erosion was thought to be possible. The thick floor, as built, covered entirely the space where this unsatisfactory material existed. Bearing tests on this material showed it capable of safely supporting any expected load. In addition to a thick floor, a trench six feet or more wide and from twelve to eighteen feet deep was dug through the soft sandstone around this portion of the lock foundations, and filled with concrete, as a cut-off wall.

A tell-tale system was made under this thick floor and connected with four-inch pipes that were imbedded vertically in the lock walls. As the lake rose after the locks were finished, the level of water in the pipes was observed. Plate IV shows the tell-tale system and the record of the observations of the water level in the holes as the lake rose, showing that in spite of the cut-off walls, lake pressure was transmitted under the lock floor. At first, the height of water in the holes indicated the ground-water level, which varied with the seasons. April 25, 1911, the Chagres was turned through the Spillway cut and the lake rose to a minimum of + 13. This level varied with the stages of the Chagres. On April 30, 1912, the sluice gates through the Spillway dam were temporarily closed and the lake allowed to rise to the preliminary level of + 50, above which it found relief over the central portion of the Spillway dam, which had been built to elevation + 50 and left at that height during the rainy season of 1912 and 1913 so as to prevent the water from rising to such a height as to interfere with work in the Central Division. On June 27, 1913, all gates were permanently closed and the lake reached its final height about December 15. It is regretted that no observation holes were inserted just north of the Emergency-dam sill, where the pressure under floor was the greatest.

Behind the lock walls, north of the thick floor, a drainage was provided that carried all seepage to sea-level, and the lock floor was made thinner.

CONSTRUCTION OF GATUN LOCKS.

Lock Excavation.

There was nothing unusual in excavating for the foundations of the Upper and Middle locks, the rock being encountered above grade in all places. The underlying rock dipped to the north and east, and was encountered at grade about 400 feet from the north end of the east wall of the lower lock, at which end the rock was 20 feet below grade, or 66 feet below sea-level, the overlying material being soft mud.

All the excavation for the locks proper, including the caisson sill, north end, was done by steam shovels, the main effort always being to keep the excavation sufficiently ahead so that the

other operations could be expanded as fast as economy indicated. This meant that the excavation for each lock chamber should be completed in time for the concrete force to spread into it as the work in the one above was nearing completion.

This concrete force, when well under way, averaged about 3000 cubic yards of concrete a day for an entire year. Everything went well, with no interference, until the attempt was made to complete the excavation for the 400 feet at the north end of the east wall, lower lock. The character and viscosity of the overlying material can be judged by Fig. 1. This excavation could be made by steam shovels on account of the fact that the rock rose to the west, and the steam shovel could always be kept on rock. It was necessary to build the floor 20 feet thick in order to bring it to grade at this end; and, even after the floor was in, the material would slide in over it, and conditions were too uncertain to commence building the walls. When this floor was gradually worked in, old rails were imbedded in a vertical position near the east edge of it, so as to reinforce a concrete retaining wall above, should that be necessary in keeping the mud off the foundation. This was found necessary, and it was with difficulty that this wall, about 16 feet high, was constructed, short lengths at a time.

The concrete in this wall was not all lost, as it formed a part of the wall section back of the culvert. This wall held the mud back so that the entire lock wall could be constructed. This experience proved conclusively that the excavation for the flare and north guide walls could not be made by steam shovel, the material being so soft that it would not support a shovel. In order to keep the locks properly unwatered while this was being done, and thus not interfere with gate erection and machinery installation, a dam was built across each lock chamber, on the north caisson sill, capable of resisting a 42-foot head of water. The dam was composed of reinforced concrete piers one foot thick and ten feet apart, which supported a water-tight timber facing.

It was decided to make the excavation for the flare and guide walls by suction dredges, and Plate V shows the depths to rock in the space to be excavated for such walls. The flare walls being retaining walls, and there being no lateral resistance

in the material overlying the rock, it was necessary to uncover the rock to depths of about 70 feet below sea-level in founding these walls. The viscosity of the material back of these walls was known, slopes as flat as 1 on 10 to 13 had been assumed by this material in excavating for the north end of the lock walls proper.

Fig. 1. Slide in North End of East Bank of Gatun Lower Locks, May 15, 1911.

On the west side it was feared that the slides would break back to the East Diversion, if uncontrolled, and on the east side would disrupt the railroad connections over which all material came. An examination of the rock contours represented on Plate V will show that each flare wall crossed a depression in the rock. This map also shows that rock would be encountered 160 feet east of the east flare wall at about 40 feet below sea-level, and 225 feet west of the west flare wall at the same depth below sea-level.

The dredges could dig to a depth of 41 feet only. The channel excavation from the sea was stopped, as shown on Plate V, so as to leave sufficient material to form a dam between such excavation and the space to be occupied by the flare and guide walls. An entrance channel wide enough and deep enough for the passage of dredges was made through this barrier, and the dredges then made the excavation for flare and guide walls, as shown on map, uncovering the rock higher than — 41 far enough back to include space for cable-way tracks. The sea water which followed the dredges was kept out of the lock chambers by the dams referred to previously.

When the dredges had completed the excavation to — 41, a clay dam was built across the channel through which the dredges had entered, shutting off connection with the sea. The dredges then lowered the water level a few feet at a time and continued the excavation. The necessary supply of water for operating the dredges was pumped into the pit.

In the rear of each flare wall the rock was uncovered before the water was lowered sufficiently to start serious sliding. The water was then held at this level until a trestle parallel to the locks was driven into the soft rock, shod piles being used. Rock was dumped through the water from this trestle, forming a retaining wall to hold back the mud. (See Fig. 2.) This rock fill was widened as fast as the mud was removed from the underlying sloping rock, the dredges being lowered at the same time. By this means, all serious sliding into the excavation for the flare walls was prevented, as well as all sliding that could seriously disrupt tracks or yards.

The rock surface under the Gatun locks was very uneven, being composed of hills and valleys; in the valleys the softest

of mud was found, corroborating the statements of the geologists that a subsidence of more than 300 feet occurred at one time at Gatun. The ground thus lowered below sea-level was afterwards covered with a sea deposit of soft blue clay. This material was found overlying red clay similar to that found everywhere on the surrounding land.

The slides down the submerged gorges crossed by the flare walls had been the source of much trouble in building the lock

Fig. 2. General View of Gatun Locks, Showing North End of Locks with Temporary Coffer-dam in Place.

walls as far north as the caisson sills on which the temporary dams were built. The two gorges crossed by the flare walls evidently formed a deeper gorge just east of the center guide wall.

The extreme depth to rock on the east side prevented the adoption of a process for the entire length of the guide wall similar to that followed for the flare walls, so the only alternative was to let the suction dredges gradually lower the water surface and remove the slides as they came in. (Plate V.) The guide

wall was to be built in the center of the excavation, and it was hoped in the beginning—if a space 140 feet wide, 55 feet below sea-level, was made, with side slopes above this elevation of 1 on 5—that serious sliding might not happen, and that the cableway tracks might be extended the full length of this wall; the remaining excavation to be done after walls were completed.

When the dredging seaward of the flare walls was completed, slopes of 1 on 13 existed in places on the east side, and after the

Fig. 3. Slide in East Bank at North End of Gatun Lower Locks, Jan. 25, 1913.

slide of January 25, 1913, occurred, slopes as flat as 1 on 20 existed. When the dredges floated at 32 feet below sea-level, all the rock foundation in the flare walls was cleared; the entire space was finally unwatered by a dredge, the dredge being grounded 55 feet below sea-level. (See Fig. 5.) Steam shovels were then placed in the pit to work over that part of the foundation in the center wall where rock is shown, and to accomplish channel excavation on the west side, where the material was stable.

Plate V shows the north guide wall built on piles driven to rock. It was intended in the beginning to make separate foundations for the piers, but the absence of any lateral resistance in the material overlying the rock caused the plan to be changed, making the foundation a continuous one, a slab of concrete reinforced with old rails enveloping the heads of the piles.

In the middle of the dry season, two months after the excavation for the walls in question had been completed, and the

Fig. 4. Slide in East Bank at North End of Gatun Lower Locks, Jan. 26, 1913.

piles for the guide wall had been more than half driven, the east bank gave way and a slide covered the greater part of the guide-wall foundation with mud from 6 to 18 feet deep, wrecking two pile-drivers. (See Figs. 3 and 4.) The sliding material was so soft that men could not stand on it, and it was necessary to drive a pile trestle to rock along the axis of the guide wall to support a locomotive crane for clearing away the mud. This process was very slow, and it was soon decided to start the grounded dredge to pumping mud sluiced to it by small monitors, sufficient water

to operate the dredge being pumped into the excavation. (Location of dredge shown on Fig. 5.) The entire foundation was finally cleared in March, 1913, thus completing the excavation for the Gatun locks and approach walls. Of course, the founda-

Fig. 5. North Approach Wall of Gatun Lower Locks. Dredge Grounded 55 Ft. below Sea-level.

tion slab for the guide wall was pushed along as fast as space was available, and was finished about the time that the excavation was finished.

Placing Concrete—Gatun Locks.

The engineering problems involved in the construction of the Gatun locks, after the excavation was completed, were not more difficult than many engineering problems in other places; the marked difference was the required speed of work in order to complete the task in the specified time.

There are more than 2,000,000 cubic yards of concrete in the one structure, the flight of locks at Gatun; and this in a contracted space in which only one plant and one organization could be used. On Plate VI is shown graphically the rate of placing

concrete in these locks. During the year June, 1910 to June, 1911, 950,000 cubic yards were placed, an average for the entire year of about 3000 cubic yards per working day of twelve hours. Commencing about January, 1912, concreting operations were almost nothing for a year, while the troublesome excavation described for the north flare and guide walls was being made. In order that this excavation should not delay the work of installing gates and machinery, it was necessary to place between August 24, 1909, and December 31, 1911, 1,760,000 cu. yds. of concrete.

All engineers know that forms are nearly always the determining element in making progress in placing concrete; consequently, that element of the problem was given most careful study. It was decided, in the first place, to lay concrete principally by cableways. The side walls were 45 to 50 feet wide at the base, and the center wall was 60 feet. The objection to using cableways in contracted places was thus eliminated, and the advantage of having means of handling the fixed irons and materials anywhere in the lock space was marked. Duplex cableways with main cables 18 feet apart were finally decided upon. This fitted in with 36-ft. monoliths, one position of the cableway building an entire monolith, or possibly one in each wall.

With the delivery lines 18 ft. apart, the towers could be so placed, with respect to a 36-ft. monolith, that no concrete delivered on these lines would be more than 9 ft. from its final position. The concrete was wet and flowed to its final position without any rehandling. With bottom-dump buckets, discharged by the cableway operator, concrete was placed very expeditiously and economically. In the beginning, side-dump buckets were used, but the bottom-dump proved the best. The writer would not now change, essentially, the plant and method followed in placing concrete in Gatun locks.

Cost.

The relatively high cost of concrete in the Gatun locks was due to the cost of material. Stone and sand were procured down the coast, the former 20 miles and the latter 40 miles from Colon. The relatively excessive rainfall—237 inches the first year at Porto Bello—and other physical conditions, including a very refractory stone, caused the cost of local production of crushed rock to be high; and the creation of a water-transporta-

tion plant capable of delivering across a portion of the Caribbean Sea more than 3000 cu. yds. of rock and 1500 cu. yds. of sand per day, and 3000 bbls. of cement per day from Colon to Gatun —the cost of which plant was all absorbed in the material— caused the ultimate cost of sand, stone and cement to be high. In addition, the cost of opening up the old French Canal from Cristobal to Gatun, the cost of providing and operating the extra plant for transporting the material from the unloading docks to the concrete mixers, 1700 ft. away and 60 ft. above such docks, largely increased the cost of materials. The decision to procure sand and stone down the coast from Colon, thus relieving the Panama Railroad of an excessive service and insuring an independent supply, was made early, and was based largely, so the writer was informed, upon transportation needs of the other parts of the work, leaving the Panama Railroad free for this and for trans-continental freight business. It was not known at the time this decision was made when the elevation of Gatun Lake would force all traffic to the relocated line of the Panama Railroad, which line at that time was not planned as a freight-carrying road. It was known that this would make the cost of sand and stone for the Gatun locks relatively high.

Forms.

Steel forms were finally decided upon for the lock-wall monoliths, as well as for the culverts and all openings of frequent occurrence. General drawings showing the lock-wall forms assembled are shown on Plate VII. When the work first started, alternate monoliths were built, but it was soon decided to place booms on the form towers, for handling the form pieces, and to build monoliths consecutively. One of the difficulties encountered had been the transporting of the pieces for the sides and backs of forms. The end construction and the boom on forms solved the problem of handling the pieces forming the sides; and brackets placed on the tower forms, as shown in Fig. 6, solved the problem of transporting the forms for the back steps.

It required about a week to build a thirty-six-foot section of lock wall to full height. As soon as this section had set, the cableway would remove the back-step forms and place them on the brackets, as shown; then the side form would be unbolted and the pieces placed about 40 feet ahead by the boom on the

form, as shown; side forms being used on one end only, after the first monolith was built. The front form, in one piece, would then be withdrawn by screws from the concrete; the tower carrying it and the forms for back steps was moved along on the tracks for 36 feet; and the front lined up, with the screws, under the direction of an instrument man. The side forms and brace would then be placed by the booms on the form. The vertical

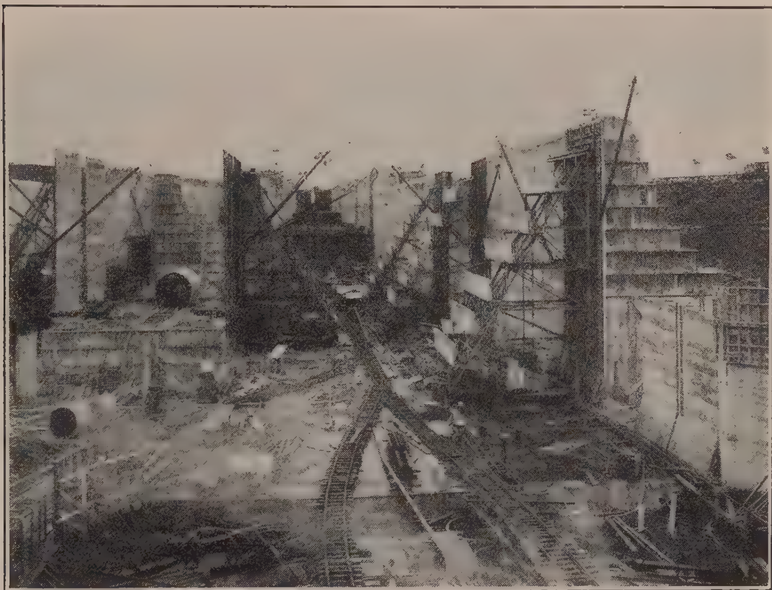

Fig. 6. West Chambers of Upper and Middle Locks from Gatun Lower Locks.

part of the back of side walls, where the rock was close and bracing easy, was generally built of wood. The forms for steps were placed by the cableways when needed.

A monolith form could be dismantled and set up ready for concrete in less than two days. This included collapsing and moving forward the forms for the 18-foot culverts. A monolith in the side wall contained 3500 cu. yds., and in the center wall 4500 cubic yards. There were four duplex cableways for placing concrete, and nine monolith forms, with the result that cableways were seldom kept waiting for forms.

The wall forms and many collapsible forms for special

openings and tunnels were designed on the work. A general specification was gotten out for a collapsible form for the 18-foot culvert. Enough of the bottom of the culvert was to be struck to template to provide for a track; and the specifications called for a form for the remainder of the culvert, mounted on a truck, that could be collapsed on the truck. A special design was gotten out by a bridge company, meeting these specifications, that proved very satisfactory. The bridge company patented the

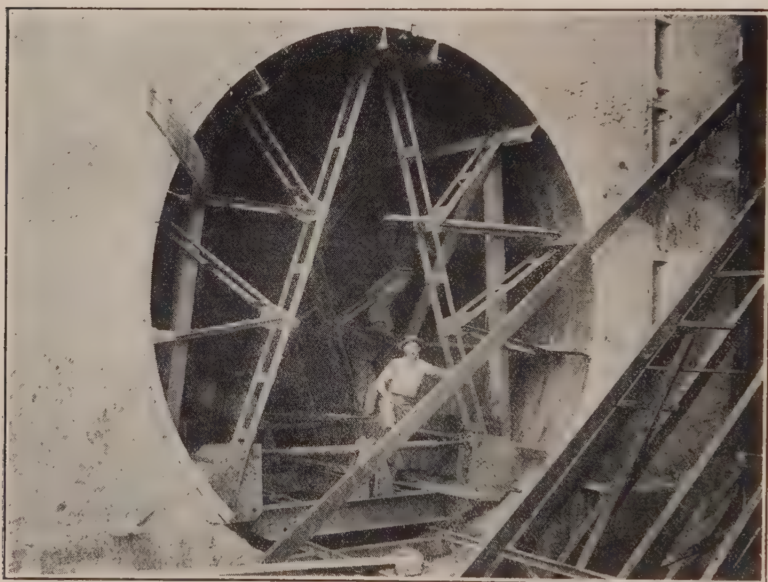

Fig. 7. Collapsible Steel Forms for Construction of 18-Ft. Diameter Wall Culverts, Gatun Lower Locks.

form. (See Fig. 7.) These forms were made in 12-ft. sections, and three of them run together provided for one monolith. The lock-wall forms were transferred from upper to lower lock levels by means of incline tracks.

Setting Temperatures of Concrete in Large Masses.

The lock walls have gravity sections, and it is seldom that such large masses of concrete are laid, so it was decided, as a matter of record, to obtain the setting temperatures of this concrete. On Plate VIII is shown the location of the thermometers

imbedded in the side and center walls. This plate also shows the temperature curves as indicated by the several thermometers. The thermometers were spirals of fine wire of high resistance in water-tight glass tubes, protected by steel casing. The principle of the thermometer depends on increased resistance with a rise of temperatures. The electric current for the thermometers was supplied from storage cells whose electromotive force was practically two volts each. These thermometers were calibrated by comparing them with mercury thermometers in an oil bath. An examination of the plate shows a maximum setting temperature of 131 degrees, and that it requires about one year for the concrete to reach normal temperature. The Gatun locks were built in monoliths 36 feet long, with contraction joints. No contraction cracks were noted except in the first monolith in the center wall in the crown of the culvert, where there is an abrupt change of section. Steps were immediately taken to prevent this in the remaining monoliths by inserting old steel rail as reinforcement. After that no further cracking was noted.

Construction Plant—Gatun Locks.

The decision to obtain the crushed rock and sand on the Atlantic Coast twenty and forty miles, respectively, from Colon, to transport same by barges across the Caribbean Sea and up the old French canal and as close as practicable to the lock sites, largely determined many features of the plant. The liability of storms on the Caribbean, and the consequent chance of there being times of a week or ten days' duration when navigation would be impracticable, and the desire to eliminate all chance of a scarcity of material, due to quarry or transportation breakdowns, were the factors that required provision for a large storage of sand and stone—to wit, 200,000 cubic yards of stone and 100,000 cubic yards of sand. This led to the adoption of cableways as the unloading device. Plate IX shows the general layout of this plant.

By dredging a channel connecting the old French canal with the French East Diversion, access was made to a wharf site as close as practicable to the locks. The material, however, when unloaded at this wharf into the storage piles and into the cement shed, was about 1700 feet from and 60 feet below the centrally located mixer plant.

The problem of getting these materials into the mixers in proper proportion was finally solved by installing an automatic electric-railway system, running in a loop line, under the cement shed, under the storage piles of sand and stone, thence to the foot of an incline leading into the mixer building, thence around a curve and back. (See Plate IX.)

The mixed concrete was delivered in buckets on small flat cars that were hauled to the various cableways by electric locomotives. The automatic cars were individually motor driven,

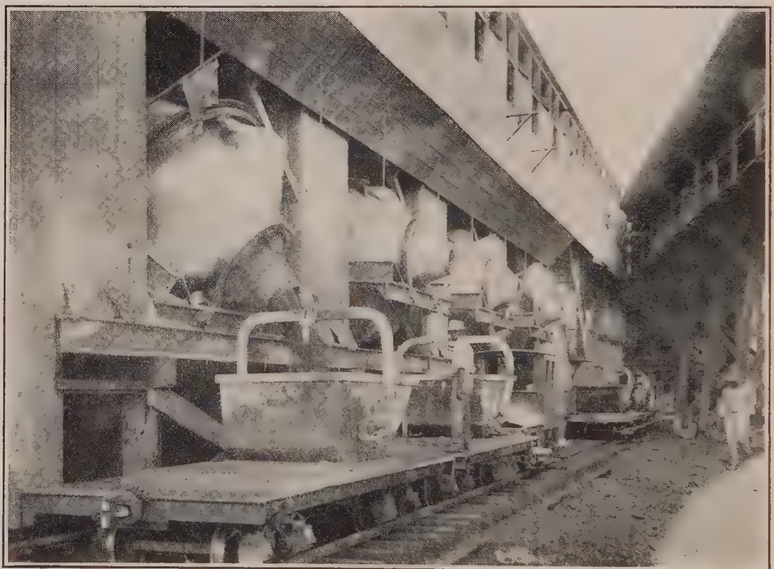

Fig. 8. Concrete Mixing Plant, Gatun.

each having a capacity of 80 cubic feet of stone, sand and cement, and were of the hinged side-door type. Each car was driven by two constant-speed alternating-current motors of the enclosed type. The motors were operated by a three-phase current, 25-cycle, 220-volt pressure, taking current from overhead trolleys. The normal speed of the cars was 300 feet per minute. The cars were automatic in taking up and maintaining a constant speed, and were started and stopped by the simple operation of a knife switch by the men stationed in the tunnels under the cement shed and storage piles and in the mixer building.

The cycle of this car was as follows: First, under the cement shed, where it was stopped, a charge of cement let down from above, and the car started again; when it was under one of the hopper valves in the sand tunnel it was stopped and the sand compartment filled by gravity; then it was started again and similarly stopped for its stone charge. When started from there it was not stopped until it was over a mixer, where it was stopped by a man in the mixer house, discharged, and started on a new cycle. After the correction of several serious mechanical defects

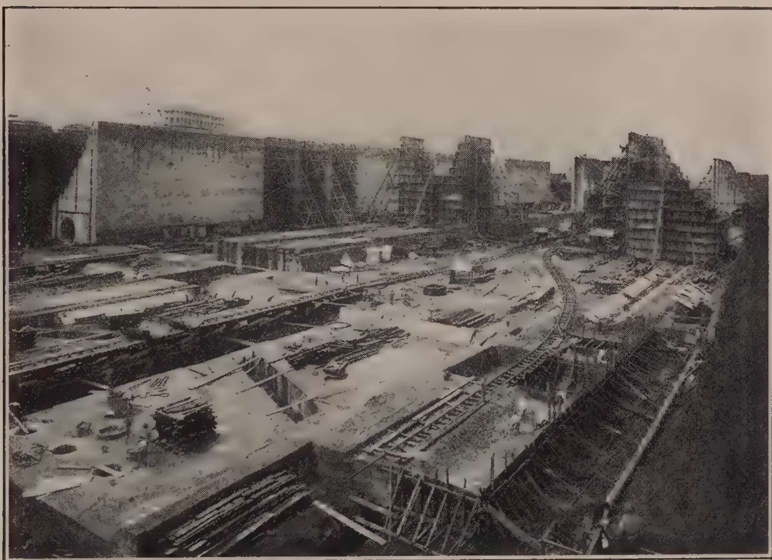

Fig. 9. Gatun Upper Locks, Looking South from West Bank.

in these cars, they did most excellent work. More than 1,000,000 tons of material were transported over this automatic road in one year.

There were no unusual features in the mixing plant except the number of two-yard mixers—8 in all; four mixers discharged on one side of the building, and four on the other. The locomotives hauling mixed concrete to the cableways were of the electric mine type. Fig. 8 shows the mixer building, flat cars with space for loaded and empty buckets, and the hauling locomotives. It was expected, when the plant was being designed, that

when form difficulties were at a minimum, it would place as much as 2200 cubic yards of concrete in a nine-hour shift. The unloading and lock cableways, the mixers, the cement unloading cranes, pumps, etc., were operated electrically. A detailed description of the construction plant will be found in the Engineering Record of July 17, 1909.

In addition to the principal plant as described above, an auxiliary plant of two 2-cubic-yard mixers, steam driven, was

Fig. 10. Gatun Middle Locks, Showing Forms for Culverts.

erected at the south end of the locks. This plant had overhead storage bins for 200 cubic yards of rock and 100 cubic yards of sand, which materials were dumped into the bins directly from standard-gauge cars which had been loaded at the wharf. The mixed concrete was hauled to its destination with narrow-gauge steam equipment.

This plant was built primarily for building the south approach and flare walls, which could not be reached by the cableways. It proved very useful in placing the floors in the locks, dumping the concrete directly from cars into place. A low

trestle was built for a considerable length of the lock floor, and a strip of floor about 15 feet wide dumped; then the track was shifted to the concrete, and, by throwing the track on set concrete, the entire floor, including the wall foundation, was placed. Figure 9 shows the method of placing concrete in the lock floors and in the foundation of lock walls, including enough of the 18-ft. culvert for tracks to carry the culvert forms. Figure 10 shows a line of forms for connecting the lateral culverts under the lock floor with the 18-ft. culvert in the wall. These were all placed and concreted in at one time. The broad-gauge track to the left of these forms carried a locomotive crane that excavated the trenches for the lateral culverts, loading the material on a standard car on the same track. The material which had been previously blasted was excavated from all the trenches in one lock simultaneously; i. e., for one position of the loading track a length of about 15 feet would be excavated in all the trenches, then the track would be thrown. This process enabled the floor to be placed as the excavation proceeded.

The concrete for the north approach wall was mixed by the main plant and dumped by the cableways into a hopper, from which the narrow-gauge dump cars, hauled by steam engines, were loaded. These cars ran out on a low trestle supported on the foundation piles, and dumped the concrete forming the bottom slab of that structure into forms on either side of the trestle. Then the track was shifted onto set concrete and the remainder of slab dumped directly.

The concrete in the piers of this guide wall was placed by locomotive cranes with long temporary wooden booms. These cranes could pass through the arches in the piers and ran on a track on the bottom slab. The girders for the spans were placed by these cranes. Forms were suspended from these girders, a track was laid on the center girders, narrow-gauge steam equipment lifted on to this track by the cableways and the concrete for encasing girders and making roadway was dumped directly from the cars, which took their concrete from a hopper supplied by the cableways. (See Fig. 11.)

Construction of South Guide Wall.

A large part of the south guide wall was founded on piles. The depth to rock was so great that piles could not be driven to

it, and the underlying material was such that settlement was expected. The wall was cellular and built of reinforced concrete, and was of as light construction as practicable. A heavy reinforced slab of concrete encased the heads of the piles. The foundation slab and the superstructure were built in 60-ft. lengths, these sections being free to settle independently. Holes were left in the bottom slab, so that the cells could fill with water when

Fig. 11. Construction of Guard Wall at North Entrance of Gatun Lower Locks.

the lake should rise; these cells were rectangular and about 13 ft. by 16 ft. in section.

The construction plan was to build the wall to a certain height for its entire length, then complete it.

Settlement soon began and was not uniform in character; the wall showed a tendency to lean to the east, which leaning increased until it demanded a remedy, and that before the top section of wall was built. The remedy adopted consisted in closing the holes in the foundation slab under the cells or rooms along the western edge of the guide wall, then pumping water

into these cells until the extra load on the west side caused the settlement to be uniform east and west.

The amount of settlement during the early construction work led to the fear that the wall might settle several feet at one time, the ground on either side bulging up, thus making room for such a settlement. In order to guard against this, the ground on both sides of the foundation, for a width of several hundred feet, was raised by hydraulic dredges so as to counterbalance the weight of the wall. No abrupt settlement occurred and the wall was finally completed.

It was first thought that the settlement would grow less as the lake rose, submerging the guide wall, which may have been true in so far as the relative elevations of bottom of wall and surrounding ground were concerned, but the settlement as shown by the elevation of the top of wall did not decrease, but showed a tendency to increase until the lake reached its full height, indicating that the weight of the water probably compressed slightly the entire lake bottom in that vicinity.

The wall was built to full height, but not finished. The reinforcing rods were left so that additions could be made if necessary to level up the top after settlement should be complete.

CONSTRUCTION OF GATUN DAM.

Dam Sections.

The dam, between the locks and the range of hills on the west side of the valley, is 8200 feet long, including a hill in the center of the valley called "Spillway Hill", and is composed of three parts: the earthen dam across the east valley between the locks and Spillway Hill, the masonry spillway dam across a cut made through Spillway Hill, and an earthern dam extending from Spillway Hill to range of hills on the west side of valley. (See Plate I.)

Plate XIII, Fig. 1, shows the section of earthen dam proposed for Gatun Dam in the minority report of the International Consulting Board. This board did not have time to investigate the bearing capacity of the material on which the dam was to be built, and the section recommended presupposed foundation material that would carry safely an earthen fill 135 feet high, with a 1 on 3 slope on one face. The 1 on 25 slope on the other

face was for the purpose, it is understood, of keeping the hydraulic grade line well below the surface, and as an extra factor of safety.

From the character of the material under the dam, as shown by borings, and the excessive amount of clay in the material available for the hydraulic fill in the center of the dam, two conclusions were tentatively reached: first, that a hydraulic fill made of the material available could not be maintained on a 1 on 3 slope; and, second, that the material underlying the dam was soft, and consequently had very little bearing capacity.

The first step toward the section actually followed in building the Gatun Dam was the proposition to build the rock fill as shown in Plate XIII, Fig. 2, thus making it practicable to flatten the lake face slope to 1 on 5, at which slope it was thought a hydraulic fill could be built with available material. Experience gained on other parts of the canal soon led to the thought that the controlling element in determining the section of the Gatun Dam was the bearing capacity of the material underneath the dam. To meet this condition, it was planned to extend the rock fill on the south face, as shown on Plate XIII, Fig. 2. This change was approved in September, 1907. While this section maintained the 1 on 25 slope of original section, the need of it was never apparent, and authority was later obtained to change the slope of the north face to about 1 on 10.

As the work proceeded, it became more and more apparent that the bearing capacity of the material under the dam was the factor that would control the slopes where the dam crossed the deep gorges, and the need of building the dam 50 feet higher than the lake level was questioned. An excess of height simply added weight on a poor foundation. The writer submitted on January 3, 1908, two sections for the Gatun Dam, Plate XIV, Fig. 2, and Plate XIV, Fig. 3, and expressed a preference for Plate XIV, Fig. 3. The construction of the dam to January, 1908, had been in accord with these sections, the variations from the section shown in Plate XIII, Fig. 2, having been previously approved in detail. Plate XIV, Fig. 3, approximated as closely as it was practicable, on account of work already done, to a dam with uniform slopes on both sides, which is thought to be the best section for an earthen structure built

on soft material, thus making no violent changes in the loading on any part of the foundation. These sections were submitted to a Board of Consulting Engineers, which Board recommended the section shown on Plate XIV, Fig. 1. The height of the dam was a compromise between the two sections submitted, and was 20 feet lower than proposed in the Minority Report, International Consulting Board, and 10 feet higher than shown in Plate XIV, Fig. 3. The north slope was the same as in Plate XIV, Fig. 3, to + 95, with four different grades on the south slope. The top 15 feet of the proposed section was rock.

Experience as to settlements and slides, as the work progressed, showed that the section shown on Plate XIV, Fig. 3, was best suited to the locality; and that part of the dam across deep gorges was built practically with that section; the core of the dam was made of hydraulic fill to + 90, and of red clay from there to the top. The settlement of the dam where it crossed the deep gorge on the west half, due to consolidation in the dam itself and the material under it when the red clay fill was placed on the hydraulic fill, showed the wisdom of carrying the core to the top of the dam with impermeable material, as shown on Plate XIV, Fig. 3. Otherwise, the rock fill would have been below the lake level in places. This section was varied in the far west part of the dam, where the underlying material was harder, and the construction of that part of the dam was started with slopes of 1 on 5.

Tests of Material Available for Dam Construction and of Material Underlying Dam.

While those members of the International Board of Consulting Engineers who had recommended a lock canal had made sufficient investigations to satisfy themselves that it was practicable to build a stable and satisfactory dam across the Chagres Valley at Gatun, it was determined, as an extra precaution and as a matter of record, to make a series of experiments similar to those made at Clinton, Mass., for the Metropolitan Water Works, as well as exhaustive tests of the material underlying the dam. The building of the dam proceeded, however, in accordance with previously approved plans, while these tests and experiments were being made.

The first-named experiment involved the building of two

experimental dams, with slopes and dimensions similar to those of the proposed dam, on a one-twelfth scale, utilizing similar material and placing it by the hydraulic method. Each experimental dam was subjected to a head corresponding to its scale. Seepage and saturation tests were made. Samples of materials were taken from the experimental dams as actually built, and mechanically analyzed. In the first experimental dam built the material was all pumped in from the down-stream edge, allowing it to grade itself, the finer material being on the lake slope. In the second, the material was pumped from both sides, the finer material naturally being deposited in the center of the dam. Both experimental dams proved that material was available for building a dam relatively impermeable. The details of this work are on record in the Annual Report of the Isthmian Canal Commission, 1908-1909.

Tests of Material Underlying the Dam. Thorough investigations were also made by borings (obtaining drive samples) and by test pits, with a view to determining the character and water-tightness of the material underlying the dam. A test pit was dug in the east half of the dam site to a depth of about 80 feet below sea-level, the seepage into this pit determined, and the material actually encountered compared with the materials found in the borings made in the two gorges crossed by the Gatun Dam. From these examinations the conclusion was drawn that the material underlying the Gatun Dam was relatively impermeable. A test pit was sunk into the rock on Spillway Hill to about 33 feet below sea-level, for the purpose of determining accurately the character of rock on which the masonry spillway dam would rest. Pumping out this pit and afterwards filling it to 30 feet above sea-level from the water supply system at Gatun, and observing the loss of water through crevices under a 30-foot head, furnished data as to the water-carrying capacity of the crevices in the rock. This was for use in determining the cut-off walls necessary and the drainage below the spillway dam, so as to protect the floor of the spillway channel from upward pressure. The experiments resulted in covering all exposed rock in Spillway Hill above the dam with concrete or a blanket of clay, thus preventing the lake water from coming in contact with such rock.

As stated before, the construction of the dam was in the meantime proceeding. The rock fill on the south toe was following the section on Plate XIII, Fig. 2, and that on the north toe on Plate XIV, Fig. 2, authority having been previously obtained to drop the north slope 30 feet at the 60-foot contour of the original Consulting Board section.

An examination of Plate I will show that the Chagres River, when dam building commenced at Gatun, was flowing through three channels to the sea, viz., its own, the old French canal,

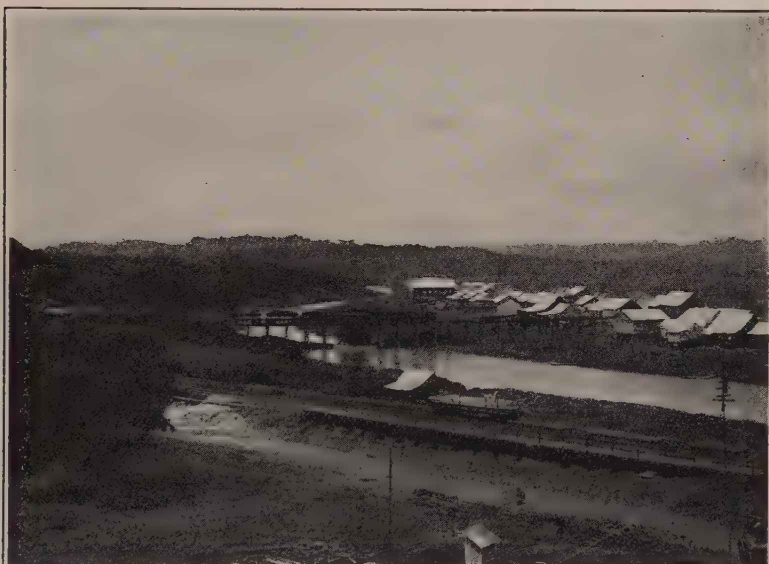

Fig. 12. Closing of the Chagres River at Gatun, Aug. 10, 1907.

and the West Diversion—the latter, a channel dug by the French in the attempt to carry out their plan which contemplated a dam at Bohio, ten miles further up the valley. As soon as the dam site was cleared, shovels were started cutting a channel through Spillway Hill, and the Chagres was shut out of its own channel and the old French canal. This enabled work to start on the east half of the dam. The first work was to clean out thoroughly, by suction dredges, the old river and canal beds within the dam site; to make a steam-shovel cut about 20 feet wide and 15 feet deep along the axis of the dam;

and to remove, by steam shovel, the top surface of the dam site to a depth of two or three feet for a width of about 400 feet on either side of the axis. The stumps had previously been blown up and removed. The central ditch and surface cleaning were carried up the side of Spillway Hill with reduced widths. Banks of old streams were flattened, and every precaution taken to prevent the existence of planes along which water

Fig. 13. Discharge Pipe from Dredges Placing Hydraulic Fill in West Section of Gatun Dam.

might travel. The surface of the cleaned ground along the axis of the dam was broken up by picks, or ploughed.

The general construction plan for the Gatun Dam was to drive a trestle approximately along the 30-foot contour on each slope, fill this trestle with rock and complete the slopes away from the center with permeable fill, rock, etc., from the canal excavation. The rock fill on the south side of the east half of the dam was carried to + 60, as shown on Plate XIV, Fig. 3, before the hydraulic fill had progressed to any appreciable extent, except in the stream beds. Between the fills thus made

and extended, the central part of the dam was built by suction dredges. After a slide at the Necaxa Dam in Mexico, an effort was made to increase the relative amount of dry fill in the dam. The exact ratio of dry to wet fill as determined by borings is shown on Plate X. Both dry and wet fill were placed at the same time, and the dry fill of course overlapped the wet as it was pushed toward the center. The face of this dry fill was kept as high as practicable and depended on the rate of delivery of the two classes of material, as well as upon the bearing capacity of the underlying hydraulic fill. An effort was made to overlap the wet fill with a face of dry fill from 10 to 15 feet high. The weight of this material with trains running over would either compact the underlying wet fill or force it to the center, where the softest of it could be wasted through the drain pipes. Figs. 12 and 13 show dam under construction.

Drain Pipes.

The surplus water was taken off through 20-inch pipes. These pipes were brought into the ponds, existing between the banks of dry fill, in various ways. Figure 14 shows the general method followed. After a drainage system was once installed, additions in short lengths were made to the vertical part of drain pipe as the hydraulic fill increased in height. By this means the depth of the pond was entirely under the control of the construction force. If the material being delivered by the dredge contained too much clay for proper and quick consolidation, the depth of the pond could be decreased, or it could be increased and all the material saved in the dam.

Generally speaking, the material available for building the Gatun Dam had too large a proportion of clay, which necessitated wasting through the drain pipes a large percent of the output of the dredges. The material kept in the dam could not be maintained ordinarily on a 1 on 5 slope in a wet state. However, flatter slopes than 1 on 5 were necessary across the deep gorges, on account of the character of the underlying material.

In placing the hydraulic fill in the dam, relay pumps were inserted in the line, when the distance or lift or both demanded it. Material was transported in this way as far as two miles and lifted 100 feet, two relays being used. Plate XI shows a typical arrangement of the discharge sections and the delivery

lines from the dredges. The discharge sections were shifted continuously. Figure 13 shows the typical condition of dry fill overlapping the wet, consolidating it and retaining it.

Slides in the Gatun Dam.

Where the rock on the south toe crossed the old French canal, slides toward the center of the dam occurred, and furnished the first actual experience as to the bearing capacity of material under the dam. There were five slides of this rock, due to the movement of the underlying material in the bottom of the old French canal. Figure 15 shows these slides. In order to bring this rock to elevation 60 without slides forcing the rock to near the center of the dam, it was necessary to bench

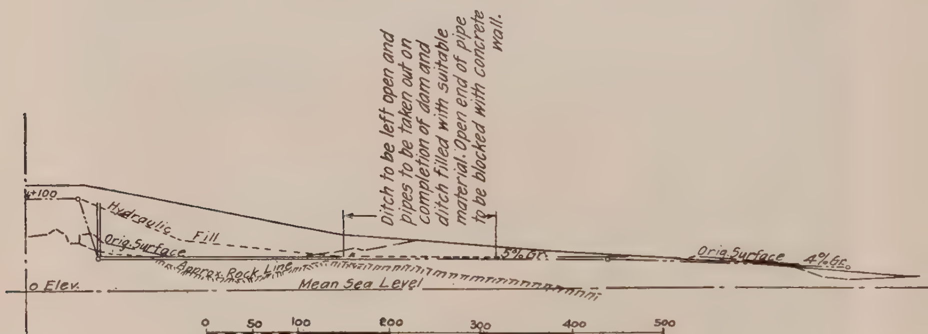

Fig. 14. General Method of Draining Hydraulic Fill.

such fill in the manner shown on Plate XIV, Fig. 3, which accounts for the usual shape of the rock section.

Until the dam was nearly its full height, all other slides were local and confined to relatively small areas of dry fill, sliding toward the axis into the wet fill. While these were many and troublesome, and often resulted in cars going into the wet fill, this was expected, and the chance of such accident was of necessity taken in consolidating the hydraulic fill. (See Fig. 16.)

When the dam section east of the spillway was nearing its final height, a subsidence occurred at the top, and both slopes moved from the center outward, involving a length of about 1000 feet of dam built over the softest part of the dam foundation—that lying between the old French canal and Spillway

Hill. The movement was greater to the north than to the south. Plate XII shows both the lateral and vertical movements on the several contours indicated. Lines of hubs had previously been established on these contours. Hub No. 6 on the + 60 line moved 15.2 ft. north and was lifted 1.13 ft. The subsidence at the crest or the movements near there were not determined. The north slope of the dam was then being built with a slope of 1 on 16 from 30- to 60-ft. contours, and with a 1 on 8 slope from the 60- to the 90-ft. contours, following the slopes on Plate XIV, Fig. 1.

Fig. 15. Slipping of South Toe of Gatun Dam, Nov. 21, 1908.

Exhaustive examinations were made by borings through the section of the dam affected, the holes being cased throughout with 2½-inch pipe. These borings were carried to rock. From time to time the casing was filled with water and the rate of lowering recorded. Drive samples of the materials in and under the dam were taken when the character of the materials changed; otherwise, at regular intervals. In addition, record was kept of the number of blows necessary for a 100-pound weight, falling three feet, to drive the core barrel, hanging free within a casing, one foot and two feet into the material at the various depths. These bore holes were washed down a certain distance, the operation stopped, then the driving test made and

the core sample taken. That portion of sample affected by wash-water was rejected. Plate X, herewith, shows the result of these explorations, and indicates that the material under the dam was softer than in it, after the latter had had time to consolidate. From the record of these borings and from the fact that there was no hydraulic fill under that part of the south slope that moved, the writer drew the conclusion that the movement involved material under the dam. The slope from the dam into the Spillway cut, south of Spillway site, was quite steep, and a pile bridge across that cut was shortened

Fig. 16. Slide of Dry Fill toward Wet Fill, Gatun Dam.

seven inches during the movement. Steps were immediately taken to lessen this slope, and it was then decided to adopt the uniform slope on the north face of the dam and build up the swamp area north of the dam proper. After these steps, no further sliding occurred in this part of the dam.

The next slide was on the south face of the west half, where the same overlaps some low hills that put out from the main range paralleling the valley. The slope here had been reduced to 1 on 5 on account of the dam foundation being thought secure, the slope of 1 on 5 being considered sufficient to maintain the hydraulic fill. Since this slide was accompanied with a bulging up of the lake bottom south of the dam, it was consid-

ered as originating in the clay covering of the hill side, there being very little lateral resistance in the material in the flat immediately south of the foot of the hill. This movement caused the slope in this part of the dam to be flattened to about 1 on 8, in addition to building up the ground by suction dredge south of this part of the dam to prevent bulging. Decision was also reached, at the same time, to flatten the corresponding slopes on the north face of this part of the dam.

This work, however, had only been started when, on August 28, 1912, a slide on that face occurred, the crest of the dam dropping about 20 feet for a length of about 800 feet. Plate XV shows in section the extent of this movement. The conclusion was reached that this slide probably had its origin in the hydraulic fill itself, showing that a slope of 1 on 5 was too steep for a hydraulic fill made of a material containing so large a proportion of clay as that available for the construction of Gatun Dam. The toe of the dam was immediately pushed to the north with a rock fill and the slope flattened to 1 on 8.

The most trying conditions in a hydraulic-fill dam are during construction, when everything is lubricated. After such a dam has been built, its factor of safety increases rapidly as it dries out. Longitudinal sections of the Gatun Dam along its axis were made after its completion, drive samples taken, and the driving tests previously described made; the results show a continual compacting of the material under and in the dam, the original ground surface being found in places fifteen or more feet below its original position. This, of course, resulted in lowering the crest, which was later brought to grade. The settlement was quite rapid immediately after the dam was brought to full height, but gradually diminished. Plate XVI shows the result of explorations made on a section of the Gatun Dam where it crossed the ancient deep gorge west of Spillway Hill.

CONSTRUCTION OF THE SPILLWAY AND DIVERSION OF THE CHAGRES.

Barring the assertion of the Chagres on one occasion of its pristine right to go where it pleased during floods, and its election to pass through the Spillway cut when it was not expected,

the excavation for the site for the Spillway Dam and channel was attended with no unusual difficulty. These structures are founded on argillaceous sandstone, and it was necessary to cover all the exposed rock surfaces with concrete, to protect them from scour and from the air. It was also considered essential to complete the channel below the dam and the foundation of the dam before the Chagres was forced into this channel, because after that it would be necessary to reckon with the river in completing the work. The Spillway channel was, therefore, completed, and as much of the foundation of the dam placed as possible; in addition, the stubs of small piers were built 20 feet apart along the entire upper face of the dam. These piers were high enough for their tops to be out of the water in the dry season. Grooves were left in both faces of the stubs.

The rate of progress on the Spillway Dam was determined by other features of the work, such as the completion of the upper gates of Gatun locks and the completion of the dry excavation in Culebra Cut. While the Chagres River was running through the Spillway channel, work was continued on both ends of the dam during the dry season, protected by cofferdams practically parallel to the channel. In this way the two ends of the dam were pushed out to the 300-ft. section left in the center for the passage of the Chagres. Such construction was stopped at elevation + 45.

As soon as the time arrived to close the central section of dam, the plan was to begin in the dry season, build the piers to a height of 35 feet, which was 45 feet above sea-level, continuing the grooves to the top, then build a railroad bridge on the piers. Three of these piers were built large enough each to contain an 8-ft. by 18-ft. opening, in which it was proposed to place valves with operating machinery. These valves were borrowed from the Gatun locks, in order to take advantage of this opportunity to test their design. In addition, provision was made for installing and testing one of the cylindrical valves intended for the middle wall of the locks. It was calculated that these openings would pass the waters of the Chagres for at least ten months in the year, without allowing Gatun Lake to rise high enough to interfere with this or other work. During the two months of greater rainfall it was planned to allow the

flood water to flow over an uncompleted part of the dam prepared for that purpose. Piers were carried up so as to keep the valve-operating machinery above any possible flood. The first work of building the Spillway Dam, after the piers were raised and railroad built, was undertaken in the dry season, and consisted in lowering, with a locomotive crane, heavily weighted wooden curtains down the grooves in the piers, stopping the flow of the river through that part of the foundation from the east side out to include the three piers with the 8-ft. by 18-ft. openings. A low coffer was then built on the down-stream side of this part of the foundation, preventing its being flooded by backwater from below. All of the pier masonry, except the extreme southern ends, was imbedded in the dam, and the plan followed was to build forms between the down-stream ends of these piers and dump concrete directly from cars, filling the space between these and the timber bulkheads referred to above. The space between piers was, of course, unwatered. The concrete in the ogee below was dumped from cars into chutes, and went to place by gravity. As soon as this part of dam was built to height of track on piers, the river was shut off from the remainder of the foundation by dropping curtains as before. The openings through the piers thereafter carried the flow of the Chagres, while construction work was in progress. There were no water difficulties connected with placing the remaining concrete. In order to build the piers and install the Spillway gates, a heavy trestle, at + 95, was continued across the dam. (See Fig. 17.) From this trestle two wrecking cranes placed the Stoney gates forming the regulating works of the dam. These gates weighed each about 42 tons, were constructed in the yard, loaded on a flat and hauled on the dam.

The problem of building a water-tight operating tunnel extending longitudinally through the Spillway Dam was solved by the Construction Division and consisted in building a continuous, thin, reinforced shell forming the tunnel. The remainder of dam was built leaving an air space around the top and sides of the inner shell. The inner shell was a tunnel within a tunnel. The outer shell could set without stressing the inner one. Any leakage through the outer shell fell to

the bottom of the air space and was carried by drains under the inner shell to drains below. (See Fig. 17 of Mr. Schildhauer's paper.)

Forcing the Chagres Through the Spillway Channel.

As stated above, all the flow of the Chagres prior to its diversion into the Spillway channel was through the channel west of Spillway Hill. The stream was tidal, its bed being below sea-level, and the upper end of the Spillway channel was

Fig. 17. Gatun Spillway Dam.

10 feet above sea-level. The river would, therefore, rise 14 feet before its normal flow through the Spillway channel was established. It was expected to accomplish this diversion in the dry season, but the Spillway channel was not ready and the diversion was made in the latter part of April, moderate rains having commenced. The west diversion was over the old depressed west gorge of the Chagres Valley. This old gorge had been filled with a sea deposit and the banks and bed of the channel were mud to great depths.

It was decided to drive trestles across this channel on the north and south 30-ft. contours of the Gatun Dam and dump rock from these trestles, thus damming the stream in two places, the idea being to divide the fall, created by the rising river, between the two dams. There was available an unlimited quantity of waste rock excavated from the Culebra Cut. This rock was dumped from the trains at and near the banks and gradually worked out until the contraction and the rising river

Fig. 18. Closing West Diversion, Gatun Dam.

created a current. Then smaller rock was dumped from the entire length of trestle section and distributed by the current, forming an apron on the bottom. Dumping was continued, using larger and larger stone, gradually working the fill out from the sides. When the channels at both trestles were about 80 feet wide and 6 feet deep, the current developed would carry all rock through the trestle. (See Fig. 18.) The rains were increasing, and it was decided to dump above the south trestle a few car-loads of crooked rails, thus forming an entanglement

against the trestle that would stop the rock or take out the trestle. The trestle piles had a rock fill around them about 18 feet deep. The trestle cracked, moved slightly, but held finally, and the flow of the water was stopped and both fills were carried up and widened, forming two substantial-looking dams across the west diversion, and the Chagres rose and flowed through the Spillway channel.

The space between these two diversion dams was of course

Fig. 19. Slide During Construction of Gatun Dam.

the site of the Gatun Dam proper. In order that this space should be dry, 20-inch pipes were laid under the north levee that continued that diversion dam across the valley. This levee settled the second day after the diversion dams were finished, the pipes were mashed and the drainage stopped. The space between the diversion dams filled with seepage water through the south dam, and the north diversion dam spread itself out down stream as shown in Fig. 19, piles with 30- to 40-ft. penetration moving down stream in almost a vertical position, showing that the movement was deep.

The water between the diversion dams being suddenly released, the west bank of the diversion, where the south dam joined it, caved into the old channel, breaking back through the trestle, and nearly through the levee that was built in continuation of the dam at this place. Trains were run out on the trestle and the levee rebuilt. This new fill caved in just as it was completed, leaving a lip about two or three feet wide at the top as the only barrier holding the Chagres out of the

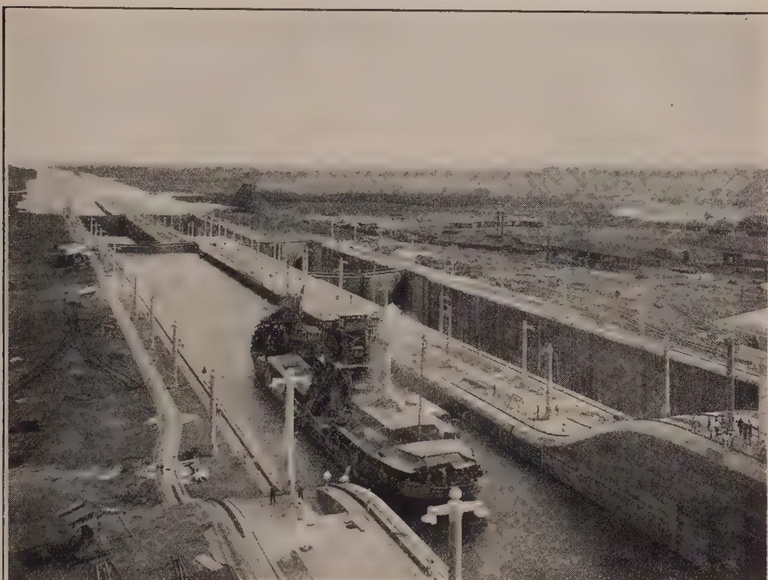

Fig. 20. Operation of Gatun Locks. Dredge "Corozal" Entering West Chamber Middle Lock. Atlantic Entrance in Distance.

west diversion. It looked as if the Chagres were to be the winner in the fight.

It was feared that if any more filling were attempted, another slide would develop taking in the entire levee and letting the Chagres through. So it was decided to utilize the suction dredges on the south side of the Gatun Dam in raising the lake bottom, just opposite this place, above the water, trusting that nothing would happen in the meantime. About half an acre was thus brought some feet above water, providing room for slides to safely break back. The diversion dams were then repaired

Fig. 21. Upstream Side of Gatun Spillway Dam.

and rebuilt, and the last diversion of the Chagres completed. Once securely in the Spillway channel, the Chagres was under complete control thereafter, except during November and December, 1912, when it flowed over a part of the incompleted Spillway Dam that had been prepared for such flow.

Figures 20 and 21 show the completed locks, dam and spillway ready for the operating force.

Paper No. 12

METHODS OF CONSTRUCTION OF THE LOCKS, DAMS AND REGULATING WORKS OF THE PACIFIC DIVISION OF THE PANAMA CANAL.

By

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The three sets of duplicate locks, constructed to overcome the difference in elevation between the Pacific Ocean and Gatun Lake, are in series, and comprise a single set located at Pedro Miguel, and a flight of two sets at Miraflores, as shown on Plate I. The Pedro Miguel locks guard the south end of Culebra Cut, and are connected with the hills on the west by an earth dam and to those on the east by a concrete core wall, founded on rock and back-filled with earth where required; for a greater portion of its length, however, the natural surface is well above high water in the lake. There are no regulating works at Pedro Miguel, regulation of the lake being controlled from Gatun; but, in an emergency it is possible to discharge 25,000 sec.-feet (708 cu. m. per sec.) through the operating culverts. The Miraflores Lake is 1.65 square miles (427 hectares) in area, and covers the entire distance between the lock sites. It is retained by the hydraulic fill dam, which connects the Miraflores locks with Cocoli Hill on the west, and a concrete dam, equipped with regulating gates, which extends from the locks across the original bed of the Rio Grande to the eastern hills.

A definite determination as to the methods of constructing the above works was unavoidably postponed, pending an approval of the recommended change in the location for the lower locks from Balboa to Miraflores. Upon the adoption of the lat-

ter site, on December 20th, 1907, studies of various types of concrete handling equipment were immediately begun, and a report was submitted on April 9th, 1908, outlining the plant that was subsequently worked out in detail and installed, with the approval of the Chief Engineer. The types of dams and regulating works, together with the methods of constructing the same, were decided upon at a later period and will be described in the proper order.

CONSTRUCTION OF LOCKS.

Plant.

Prior to the selection of Miraflores as the location of the lower locks, an arrangement had been made with the Central Division to excavate the Pedro Miguel site to reference 40 feet (12.19 m.) above mean sea level, in connection with similar work in the south end of Culebra Cut. In this way 1,071,696 cubic yards (819,377 cu. m.) had been removed at Pedro Miguel before the design of the construction plant for the locks was begun and, exclusive of the above quantity, the work to be performed by the plant as estimated at that time is shown in Table No. 1.

TABLE NO. 1.

Quantities on Which Design of Construction Plant Was Based.

	Pedro Miguel		Miraflores		Total	
Item	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.
Excavation	833,200	637,003	2,027,700	1,550,229	2,860,900	2,187,232
Concrete	745,900	570,260	1,134,000	866,972	1,879,900	1,437,232
Dredging	....	....	1,603,700	1,226,070	1,603,700	1,226,070

For comparison, the actual quantities of completed work corresponding to the above estimated quantities are given in Table No. 2; the differences are largely due to subsequent enlargements and modifications in the locks.

TABLE NO. 2.

Actual Quantities of Completed Work.

	Pedro Miguel		Miraflores		Total	
Item	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.
Excavation	1,309,267	1,001,014	2,638,563	2,017,342	3,947,830	3,018,356
Concrete	907,175	693,591	1,479,739	1,131,366	2,386,914	1,824,957
Dredging	....	....	642,350	491,115	642,350	491,115

The excavating equipment consisted of the standard types of steam shovels, locomotives, dump cars, and dredges em-

ployed for similar work elsewhere on the Canal, and will not be described here. In regard to the concrete handling plant, it was manifest, from the estimated quantities and current rate of excavation at Pedro Miguel, that the greater part of the masonry of these locks could be placed before the excavation at Miraflores would be sufficiently advanced to begin concrete work, at the latter point, on a large scale; and that it would be most economical to select equipment suitable for constructing the two sets of locks in sequence.

With the above idea in mind, and the additional condition that all materials would be delivered to the sites by rail, a plant was designed to comply, as far as possible, with the following general principles:

1st. The plant as a whole must not only be adaptable to both sites, but of adequate capacity to concentrate at each, in turn, and construct the entire work within a specified period.

2nd. The respective units to be designed for delivering the aggregates from storage to mixers, and concrete from the latter to the walls, through the least number of intermediate links and along the most direct routes. In addition they should be fitted to handle the forming, anchorage, reinforcement and excavated material, so as to utilize the plant when not engaged in handling concrete and thereby obtain greater efficiency.

3rd. In so far as compatible with local conditions and cost, the number of units should be such as to minimize the effect on the capacity of the whole of one or more being out of commission, and their relative disposition should be such as to admit the substitution of a workable unit for a disabled one, when the exigencies of the case so required.

4th. The first cost to be within reasonable limits, and a careful study made of methods and details affecting operating costs.

5th. Finally, as the estimated amount of concrete to be placed at Miraflores was approximately one and a half times the amount for Pedro Miguel, the question of economical handling should have greater weight at the former site.

Comparative estimates indicated that large storage facilities at the lock sites would provide insurance against accidents and delays in the delivery of materials more effectively and economically than the requisite additions or duplications to

the producing plant and transportation equipment. This having been demonstrated, it followed that, from properly distributed storage, the aggregates could be conveyed through movable mixers to the walls with less handling and more directly, than through one or more stationary mixing plants of equal capacity. It was also apparent that, where possible, it would be of material advantage to place the storage and handling units in rear of and close to each side wall, and thereby minimize the distance and time of handling the larger percentage of concrete.

The plant selected was composed of the following elements, which served both Pedro Miguel and Miraflores, though the handling units were differently combined for the respective sites as described hereafter:

Producing Plant.—(1) Stone quarrying and crushing plant
(2) Sand dredging and handling equipment
(3) Transportation equipment
(4) Cement storage
(5) Power-house

Handling Plant.—(1) Berm cranes for handling aggregates, mixing and placing concrete
(2) Chamber cranes for placing concrete
(3) Auxiliary mixing plants
(4) Narrow-gauge railway for transporting concrete
(5) Storage trestles for sand and stone.

PRODUCING PLANT.

Quarrying and Crushing Plant.

Four promising locations for a quarry were investigated: viz., Cocoli, Corozal, Sosa, and Ancon hills. The first two had the advantage of being in the immediate vicinity of Miraflores. The stone in Corozal Hill was found to be unsuitable, and comparative estimates for developing and operating quarries at Cocoli, Sosa, and Ancon gave results decidedly favorable to Ancon, mainly because of the large amount of overburden at the former sites. Another consideration which led to the selection of Ancon was that the rock was exposed, in a number of small quarries, on three sides of the hill, and these, in connection with numerous test pits, showed conclusively that there was ample rock of good quality and so stratified as to break

up into sizes suitable for economical handling and crushing. The relative locations of the locks and Ancon Hill are shown on Plate I. The quarry was located on the southwest point of the hill, as may be seen from Plate II. The top of the hill is 650 feet (198.1 m.) above mean tide, while the adjacent flats, on which the tracks leading to points of delivery were laid, is 20 feet (6.09 m.). Below reference 175 feet (53.3 m.) the face of the hill is irregular and the rock is covered to a considerable

Fig. 1. General View of Ancon Quarry.

depth with earth; above that elevation the slope is regular and there was a comparatively small depth of stripping. The quarry floor and crusher shed were accordingly fixed at reference 175 feet (53.3 m.) as the data obtained indicated that the estimated quantity of stone required, viz., 2,000,000 cubic yards (1,529,-118 cu. m.), could be obtained between this elevation and 400 feet (121.9 m.) and within the area shown on Plate II; the face was divided into three lifts connected by switch backs, as shown on the drawing and Fig. 1. The stone was loaded and transported to the crushers by means of standard steamshovels, locomotives and cars of 5-feet (1.52 m.) gauge; those employed in the quarry were run over the operating tracks to the stone bins

at elevation 70 feet (21.3 m.), and from there hauled up an inclined track about 600 feet (182.8 m.) long, with a gradient of 18 per cent, to the quarry floor level, by means of a Lidgerwood unloading machine, anchored at the top of the incline. A five-track yard was established on the 175-foot (53.3 m.) level of sufficient capacity to facilitate delivering stone to the crushers and provide tracks for storage, hostling, and repairs, a small machine shop being equipped for the last purpose.

The crushing plant was electrically driven, and consisted of a No. 12 and four No. 6 McCully gyratory crushers, installed as shown on Plate III. Stone was dumped from the cars directly into the No. 12, which was capable of taking sizes up to 36 by 60 inches (91.44 by 152.4 cm.) and reducing them to 5 inches (12.7 cm.) or less in size. The product of the No. 12 was discharged into a revolving screen designed to pass 2½-inch (6.35 cm.) stone. The oversizes were discharged from the lower end of the screen into the four No. 6 crushers for further reduction. The product of the screen and small crushers was carried through chutes to a horizontal 36-inch (91.44 cm.) belt conveyor, and conveyed 212 feet (64.6 m.) to the north end of the storage bins, where it dropped on to a second belt conveyor of the same size, which distributed the stone evenly along the length of the bins, or at such points as desired, by means of an automatic tripping device. A dust screen was not considered necessary when the plant was installed, but as work progressed it was found advisable to insert one between the two conveyors; the dust and fines were discharged into a pocket formed at the north end of the bin, by constructing a bulkhead, and were utilized for highway and other work. The storage bin held 1750 cubic yards (1338 cu. m.) and was made up of a strongly braced rectangular wooden bin 143 by 16 by 21 feet (43.5 by 4.87 by 6.4 meters) high, resting on a reinforced-concrete sub-structure, consisting of a floor slab, supported by columns of the proper height to give clearance for a locomotive on the loading track immediately under the bin. Trains were loaded by gravity, through twelve hand-operated chutes located a car length apart in the floor of the bin, so that the cars in a train could be loaded simultaneously. The plant was practically ready for operation in October, 1909, when an

earth slide, involving about 40,000 cubic yards (30,584 cu. m.), occurred immediately below the crusher house; the latter being founded on solid rock was not disturbed, but a portion of the foundation of a concrete retaining wall on the north side of the house gave way, and the wall had to be removed. The conveyor connecting the crushers and bin and a portion of the incline leading to the quarry-floor level were carried away; the bin was seriously threatened, but fortunately was saved without injury. Removing the slide and repairing the damage delayed the beginning of operation until February 10th, 1910. In working the quarry, 45 percent dynamite was used, the drilling being done with air-driven well and tripod drills. The former were used for drilling deep, vertical holes, usually about 20 feet (6.1 m.) back of and running the full depth of the face, while the latter drilled corresponding horizontal holes in the toe of the face to the depth of approximately 20 feet (6.1 m.); the longitudinal distance between the holes varied, and was fixed according to local conditions. The plant was designed to supply the crushed stone required for the Pacific locks, estimated to be 2,000,000 cubic yards (1,529,118 cu. m.); and, in view of the elasticity secured through large storage facilities at the locks, it was considered safe to fix its rated capacity at that of the concrete handling plant, which was 2,560 cubic yards (1,957 cu. m.) per eight-hour day. The estimated cost of delivering crushed stone in storage at the locks was \$0.96 per cubic yard (\$1.255 per cu. m.). The plant, however, supplied a certain amount of stone for the Gatun lock, municipal work, terminals and fortifications, and it was necessary to work twelve hours per day for a portion of the time. Concrete work on the locks was practically completed prior to June 30th, 1913, and on that date the quarry had produced 2,558,578 cubic yards (1,956,099 cu. m.) and was still in operation. During this period the average rate per day of eight hours was 2352 cubic yards (1,798 cu. m.); this does not fairly represent the capacity of the plant, as the output varied with the demand, and, during the two years, 1911 and 1912, of maximum demand, the average rate was 2774 cubic yards (2,120 cu. m.). The average cost to June 30th, 1913, was \$0.856 per cubic yard (\$1.119 per cu. m.) in storage. Additional details are given in Table 3.

TABLE NO. 3.

Performance of Ancon Quarry Crushing Plant.

Fiscal Year	No. of 8 hour days	Quarried, Crushed, and Supplied				Total		Unit Cost in storage	
		Pacific Locks		Other Departments					
		cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.
1910......	117	142,911	109,259	32,263	24,666	175,174	133,925	$1.502	$1.965
1911......	302	808,767	618,323	47,057	35,976	855,824	654,299	0.844	1.104
1912......	309	782,818	598,484	56,461	43,166	839,279	641,650	0.799	1.045
1913......	360	424,850	324,809	263,451	201,415	688,301	526,224	0.779	1.019
Total...	1088	2,159,346	1,650,875	399,232	305,223	2,558,578	1,956,098	0.856	1.119
1914......	Details not given					582,798	445,564	0.897	1.174
Total...	....	....	....	....	....	3,141,376	2,401,662	0.864	1.130

Note.—All unit costs given in this and following tables are division costs and include plant charges.

Sand Production.

Sand was obtained from a bay formed by Point Chame, about 20 miles (32.18 km.) up the Pacific Coast from the entrance to the Canal, a point selected after investigating carefully the quantity and quality of sand and loading facilities at numerous points within a reasonable distance. A French ladder dredge of the self-propelling type, that had been repaired at the Balboa shipways, was used for loading the sand into scows of 500 cubic yard (382.3 cu. m.) capacity, and the latter were towed to the unloading dock at Balboa. The dock was a wooden structure supporting elevated storage bins and tracks for the unloading cranes and sand trains, as shown on Plate IV. The bins held 2600 cubic yards (1,987.7 cu. m.) of sand, and covered a length of 260 feet (79.2 m.); there were three unloading cranes, similar to that shown on the drawing, which operated on runways extending the full length of the bins. Each crane was equipped with a 3-cubic-yard (2.29 cu. m.) clam-shell bucket, and the hoisting, trolleying, and bridging movements were actuated, respectively, by 100-, 20- and 15-horsepower 550-volt direct-current motors, while a small railway-type air compressor on each supplied air for controlling the hoisting and lowering brakes. The machinery and controlling devices were located on top of the crane near the front towers, so that the

operator had the bucket in view at all times. The equipment was designed to supply the requirements of the Pacific division, estimated to be 1,000,000 cubic yards (764,559 cu. m.) at an estimated cost of $0.80 per cubic yard ($1.05 per cu. m.) delivered in storage. The sand plant also supplied a portion of the sand for Gatun locks, terminals, fortifications, and other works, and the output prior to June 30th, 1913, was 1,741,196 cubic yards (1,331,189 cu. m.) at an average cost of $0.777 per cubic yard ($1.016 per cu. m.) in storage, as detailed in Table 4.

TABLE NO. 4.

Performance of Chame Sand Plant.

Fiscal Year	Dredged and Supplied				Total		Unit Cost in Storage	
	Pacific Division		Other Departments					
	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.
1910..........	126,869	96,994	108,991	83,326	235,860	180,320	$0.976	$1.276
1911..........	465,426	355,830	29,415	22,489	494,841	378,319	0.828	1.083
1912..........	509,587	389,592	55,250	42,240	564,837	431,832	0.702	0.918
1913..........	not given	....	not given	....	445,658	340,717	0.711	0.929
Total.......	....	....	....	....	1,741,196	1,331,188	0.777	1.016
1914.........	not given	....	not given	....	199,319	152,835	0.816	1.067
Total.......	....	....	....	....	1,940,515	1,483,573	0.781	1.021

Transportation.

All materials were delivered on the lock sites by rail, the Isthmian standard rolling stock being used. Those materials from the United States, as, for example, cement, lumber, rails, machinery, etc., were delivered by the Panama Railroad on exchange tracks at Corozal, and from there were handled throughout the division by the division transportation department; sand, stone, and excavated material were handled exclusively by the latter department. To facilitate the transportation within the division, a system of tracks extended the full length of the same from Pedro Miguel to Balboa; dump tracks were connected to the system at convenient points and storage yards installed where required. The division main line was about a half mile west of, and practically parallel to, the Panama Railroad; the two lines were connected at Pedro Miguel, Miraflores,

Corozal, and Balboa, so that the blocking of either would not seriously interfere with the transfer of material and supplies.

Cement Storage.

A shed of 75,000-barrels capacity was erected west of the Miraflores lock site, and connected by rail to both sites. The floor was of concrete, while the superstructure was a wooden frame covered with corrugated iron; the plan contemplated the subsequent installation of a system of steam-heated pipes for keeping the cement dry, if desired, but experience showed it to be unnecessary and the installation was omitted. Cement, in

Fig. 2. Sand Unloading Cranes at Balboa.

bags, was delivered in box cars on two parallel, depressed tracks located along the longitudinal axis of the building, and was distributed over the floor space by four overhead electrically-operated cranes. The arrangement of the handling plant was such that something less than 50 percent of the cement used passed through the shed, and the cost of handling the remaining 50 percent in and out of the shed was saved. Cement was used from the shed and replaced at a rate which would insure none remaining in storage longer than three months.

Power House.

The scheme for supplying power for operating the locks, etc., included a central station at Gatun, and a duplicate

stand-by station at Miraflores. The location of the latter was, therefore, selected, and a permanent, reinforced-concrete station built immediately, so as to utilize the electric power for construction. The installation consisted of six 400-hp. water-tube boilers, equipped with superheaters, induced draft and oil burners; the electrical machinery consisted of three (3) 1500-kw., 2200-volt, 3-phase, 25-cycle turbo-generators with the accompanying exciters, rotary converters, condensers and switch-gear. The large concrete mixers and handling cranes, sand cranes at Balboa, stone-crushing plant at Ancon, 20-inch (50.8 cm.) dredging pumps used for hydraulic filling, and a number of smaller pieces of machinery were electrically driven from the above power house. The dredging pumps were driven by motors designed for alternating current; for all other construction purposes the current was converted into 550-volt direct-current by three rotary converters, one in the central station and one each in temporary substations at Pedro Miguel and Balboa.

HANDLING PLANT.

Berm Cranes.

There were four (4) steel berm cranes, each weighing about 470 tons. The towers were 40 by 50 feet (12.2 by 15.2 meters), and were mounted on sixteen (16) pairs of standard railroad axles and wheels, for traveling along two parallel 5-foot (1.52 m.) gauge tracks spaced 50 feet (15.2 m.) center to center, as shown on Plate V. To each tower was attached a cantilever truss 150 feet (45.72 m.) long, and a 144-ft. (43.89 m.) boom, extending in opposite directions; the latter was hinged so that the outer end could be swung through an arc of 25 degrees, both vertically and horizontally. To the lower chords of each were attached runways for trolleys; the trolley operated on the cantilever was equipped for controlling all of the movements of a 2½-cubic-yard (1.91 cu. m.) Hulett clam-shell bucket that was used for excavating sand and stone from the storage piles and conveying them to hoppers on the tower. The boom trolley was arranged to convey and operate the movements of a 64-cubic-foot (1.81 cu. m.) bottom-dump concrete bucket, of especial design, and was also capable of handling forms and other materials; each trolley carried

a cage for the operator, and controlling switches, so that the operators were immediately above and in plain view of their work at all times, which enabled them to dump into limited spaces without signals and other sources of delays incident to remote control.

Directly under the trolley runways on the tower were two bins for sand and stone, respectively, of 15 cubic yards (11.5 cu. m.) capacity each, from which the aggregates flowed through gravity chutes, controlled by segmental gates, into measuring hoppers connected with the mixers below. Below the bins the entire area of the tower was floored over and protected as a storage space for 6000 bags of cement; suspended from the floor were two hoppers holding ten (10) barrels of cement each and connected by gravity chutes, with gate control, to the measuring hoppers. Cement was delivered in bags from box cars to an elevator secured to the tower framing, and from this to a horizontal conveyor operating across the concrete floor to gratings over the suspended hoppers; bags to be stored on the floor were removed from the conveyor by hand before reaching the gratings. The mixer platform was rigidly attached to the tower, lower down, and supported two motor-driven 64-cubic-foot (181 cu. m.) cube mixers, which discharged directly into the concrete buckets when placed on a movable platform hinged on the outside of the tower frame. The platform could be swung, by compressed air, through an arc that carried a bucket from a central position under the boom to one immediately under the discharge spout of either mixer; when filled it was swung back to the former position and picked up by the trolley; this was usually accomplished without unhooking the fall lines. The mixers were equipped with an electric recording instrument which showed graphically the time occupied for mixing and discharging each batch. On the record the foreman in charge was required to explain the cause of unusual delays. Experience demonstrated that the usual dumping gear, though running in oil, wore rapidly, and it was replaced by what proved to be a most satisfactory air-dumping device, which consisted of a cylinder hung in trunnions placed below the mixing platform, with the piston rod connected to the dumping shaft through a series of levers, the air being

controlled by a three-way cock located at a convenient point on the platform. Power for operating the cranes was supplied through a well protected feeder rail carried on brackets attached to the crossties of one of the crane tracks. Excepting the 40-hp. shunt-wound motors for each concrete mixer, which were located on the mixer platform, all motors were compound-wound and installed in a machinery house on top of the tower; these included 65-hp. motors, geared through two reductions to the hoisting drums, 21-hp. motors for trolleying and 15-hp. motors for the elevator and conveyor, all of which were controlled by master switches in the trolley cage. Dynamic braking was employed in the hoisting and trolleying movements, and one hoisting motor was arranged so that, after disconnecting from the hoisting drum, it could engage a traversing drum through friction clutches, for traversing the crane in either direction by means of cables anchored to the track.

The conditions at Pedro Miguel, as described hereafter, required the use of two berm cranes, only modified as follows:

The cranes were converted into balanced cantilever machines, with continuous trolley runways, by omitting the booms and substituting the cantilevers from the two remaining machines, as shown on Plate VI. The sand and stone bins from the other cranes were also added to these to provide for the material handled by two trolleys.

Chamber Cranes.

Four steel cranes of the cantilever type, shown on Plates V and VI, were employed for placing concrete. They were designated as "chamber cranes", because they were located in the lock chambers. Each crane weighed about 95 tons, and was mounted on four heavy freight-car trucks for running on two parallel 5-foot (1.52 m.) gauge tracks extending the full length of the lock floors. The towers were 56 by 40 feet (17.1 by 12.2 m.), with bracing designed for ample clearance over the inclined trestles connecting the upper and lower lock chambers; each tower supported cantilever arms 53.5 and 81.5 feet (16.3 and 24.8 m.) long, respectively, which extended over the middle and side walls of the locks. The trolley operated over a continuous runway 191 feet (58.2 m.) long, suspended from the tower and cantilever trusses, and all movements, in-

cluding the manipulation of the bottom-dump concrete buckets, were controlled by an operator in the cage attached to the trolley. Motors of 47-, 21-, and 15-hp. were located in a house on top of the tower, for hoisting, trolleying, and traversing, respectively. Traversing was controlled by a stationary switch on the tower frame, within reach of the operator when his cage was in a certain position only, the object being to prevent traversing simultaneously with other movements, to avoid torsional stresses for which the structure had not been designed.

CONSTRUCTION METHODS AT PEDRO MIGUEL.

Lock Excavation.

The Central division having excavated the site to reference 40 feet (12.2 m.), the work was transferred to the Pacific division in June, 1908, and was practically completed in November, 1909. Subsequent slides and the decision that the cost of removing a French dump, from the east berm, should be charged to lock excavation, increased the yardage and extended the period of excavation work into the fiscal year 1913. The material was chiefly rock and was excavated with steam

Fig. 3. Pedro Miguel Locks. Looking North from East Bank.

shovels and transported to dumps in trains of 10- and 20-cubic-yard (7.6 and 15.3 cu. m.) dump cars. The area excavated was south of the lift wall, where a sheer drop of 30 feet (9.1 m.) formed a dead end for the loading tracks, and, as the shovels approached this barrier, it was necessary to break the trains and switch in a few cars at a time for loading, as may be seen from Figs. 3 and 4 attached. This condition necessitated hauling all of the excavation from the south end of the lock pit and over heavy grades, in order to pass over the dike which protected the work from frequent floods in the Rio Grande and Pedro Miguel River. The amount of material excavated and average cost were as follows, exclusive of the Central division work:

TABLE NO. 5.

Dry Excavation, Pedro Miguel Locks.

	Excavated		Unit Cost	
Fiscal Year	cu. yds.	cu. m.	cu. yds.	cu. m.
1909	720,157	550,579	$0.709	$0.927
1910	298,500	228,211	1.187	1.552
1911	16,423	12,556	0.599	0.783
1912	95,156	72,749	0.302	0.345
1913	3,044	2,327	0.408	0.533
1914	----------	----------	---------	---------
	1,133,280	866,422	$0.798	$1.043

Preparing Foundations.

After the steam shovels had excavated approximately to grade, it was necessary to remove the loose rock and level the surface for the concrete, also to excavate 42 trenches for lateral culverts, each trench being 13 feet (3.96 m.) wide, 11 feet (3.35 m.) deep and 137 feet (41.75 m.) long. This work was designated as "preparing foundation" and was done by hand, the rock being loaded into skips or buckets and transferred to cars with derricks or locomotive (jib) cranes. This work was particularly expensive, as most of the trenches were in trap rock and were excavated simultaneously with placing concrete in the walls, which called for unusual care in blasting and interfered with transportation; moreover the bottom of the trenches was below the drainage system, so that special pumping was necessary. Power drills were employed almost ex-

Fig. 4. Excavation at North End of Upper Miraflores Locks.

clusively, and the total amount of rock removed in preparing the foundations was 175,987 cubic yards (134,546 cu. m.), at an average cost of $2.444 per cubic yard ($3.196 per cu. m.).

Concrete Construction.

Auxiliary Mixers.—Through delays in the delivery and erection of the large cranes, it became essential to begin operations with an auxiliary plant, consisting of three (3) portable ½-cubic-yard (0.38 cu. m.) mixers and a stationary installation of two (2) 64-cubic-foot (1.81 cu. m.) mixers placed at the south end of the excavation for the west wall, where sand and stone could be dumped directly from cars into overhead feeding bins of about 20 cubic yards (6.1 cu. m.) capacity. With this equipment the masonry was started on September 1st, 1909, beginning with the lower guide wall; the portable mixers were so placed as to discharge into the forms, while the concrete from the stationary plant was conveyed in buckets on flat cars and deposited in the forms with derricks or locomotive cranes. When the handling cranes were placed in commission, the 64-cubic-foot mixers were moved to the south end of the storage trestle in the forebay, and so located that the feeding bins

could be filled from trains on the trestle; they remained in this position until the masonry was practically completed, and mixed a large percentage of the concrete placed above the lift wall. The cost of producing concrete with the auxiliary mixers was materially larger than with the main plant; but it was necessary to continue using them mainly for the following reasons:

When the main plant and methods of operation were determined upon, the existing plans of the locks showed a comparatively small proportion of concrete above the lift walls, and the intention was to place it with derricks supplied from the berm-crane mixers. Alterations in the lock designs, subsequent to the partial installation of the plant, not only materially increased the amount of concrete above the lift walls, but added to the excavation and introduced sumps and lateral trenches, the excavation of which, during the construction of the main walls, would have seriously interfered with the operation of the narrow-gauge road. Under the circumstances, the only choice was to postpone a large portion of the forebay work until the cranes had been moved to Miraflores and depend entirely on the auxiliary plant. The consequence was that of the 907,175 cubic yards (693,559 cu. m.) mixed and placed at Pedro Miguel, 457,435 cubic yards (349,721 cu. m.), or slightly over 50 percent, was mixed by the auxiliary mixers.

Main Plant.—The arrangement of the main handling plant at Pedro Miguel is shown on Plates VI and VII. The banks on either side of the site being high and unreliable, it was impracticable to place the berm cranes back of the side walls so as to utilize them for both mixing and placing concrete. Their function, therefore, was handling the aggregates and mixing only, and for this purpose they, together with the storage trestles, were located in the forebay and a narrow-gauge railway introduced to transport the concrete to the chamber or placing cranes. With this disposition, two berm-cranes, with certain modifications, were sufficient to mix concrete for the four placing cranes and, when designing the former type, provision was made for converting these two into balanced cantilever cranes by substituting parts from the two remaining cranes, as previously described and as may be seen by comparing Plates V and

Fig. 5. Pedro Miguel Locks. View of Mixing Crane and Storage Trestle in Forebay.

VI. Thus modified, the trolleys operated on each arm were provided with their respective bins for sand and stone on the tower, and worked entirely independently of one another; the crane tracks were parallel and symmetrical with the canal axis, and the cantilever arms extended well over the corresponding storage trestles. Aside from the above alterations, and the lengthening of the discharge spouts of the mixers so as to pour directly into buckets without removing them from the cars, these cranes were equipped as previously described under the heading "Berm Cranes".

For storage, framed wooden trestles were built along both sides of the forebay, each averaging 28 feet (8.53 m.) in height and 800 feet (243.8 m.) in available length, the total storage capacity being 45,000 and 55,000 cubic yards (34,403 and 42,049 cu. m.) of sand and stone, respectively. The aggregates were dumped into storage from cars on the trestle, stone being deposited on the near side to reduce the average haul to the mixers. The layout in the forebay is clearly illustrated in Figs. 5 and 6.

The 36-inch (91.4 cm.) gauge double-track road, for conveying concrete from the mixing to the placing cranes (see Plate VII), was carefully laid with 70-pound (154.3 kilo.) steel rails, to insure speed with safety of operation, and was provided with ample switches and crossings, to facilitate the passage of trains into and out of either lock chamber. The tracks were carried from the forebay down to the lock floors on inclined trestles with a gradient of 2.5 percent. The equipment consisted of twelve 11½-ton (10,432.6 kilo.) Porter locomotives and twenty-four (24) steel flat cars, each capable of carrying two concrete buckets; both locomotives and cars were fitted with air brakes. All trains were made up of a locomotive and two flat cars, each car carrying a concrete bucket so placed that, when spotted in front of a crane, the buckets were directly under the discharge spout of the corresponding mixers, and both could be filled simultaneously. When the buckets had been filled, the train proceeded to one of the lock chambers as directed by signal, and stopped under the first chamber crane; the latter placed an empty bucket on one of the cars

Fig. 6. Pedro Miguel Locks. Concrete Mixers in Forebay, Loading Buckets.

and picked up a full one from the same car; the train then moved to the next crane, which also exchanged an empty for a loaded bucket, leaving the train with two empty buckets to return to the mixing plant (see Fig. 6). Ten (10) trains were usually operated, as a less number was insufficient for constant service of the cranes, and it was more economical to have trains waiting than to delay the mixing and placing cranes. Referring to Plates VI and VII, it will be seen that there were two chamber cranes in each lock; they were employed primarily for placing concrete, but were also used for handling forms, back-filling the middle wall, placing gate anchorage and other imbedded metal.

Performance of Cranes.—The berm cranes were designated by the letters E, F, G and H—cranes E and G being used at Pedro Miguel. The chamber cranes were numbered 1, 2, 3 and 4, respectively. The periods of operating the various units at Pedro Miguel were as follows:

TABLE NO. 6.

Working Time of Cranes at Pedro Miguel.

Designation	Working Time		Working Days
	Began	Stopped	
Crane E........	Mch. 15, 1910	May 19, 1911	363
" G........	June 13, 1910	Jan. 28, 1911	217
" 1........	Mch. 15, 1910	Jan. 27, 1912	567
" 2........	Mch. 15, 1910	Apr. 20, 1911	336
" 3........	June 13, 1910	Dec. 6, 1911	448
" 4........	July 15, 1910	May 9, 1911	258

From the above it is seen that one half of the plant, or one mixing and two placing cranes, began work on March 15th, 1910, and the other half on July 15th, 1910, and that the plant worked as a whole from the latter date to January 28th, 1911, when it became necessary to begin dismantling for removal to Miraflores. After the dismantling of the last mixing crane, the remaining chamber cranes handled back-filling and concrete from the auxiliary mixers, so that the amount of concrete handled by the two types of cranes is not the same.

TABLE NO. 7.

Performance of Cranes at Pedro Miguel.

	Berm Cranes		Chamber Cranes	
	cu. yds.	cu. m.	cu. yds.	cu. m.
Number of crane days	580.00	....	1,609.00	....
" " " hours	3,404.04	....	8,141.27	....
" " mixer "	6,652.79	....	....	....
Concrete mixed, cubic yards	452,273.00	345,774	....	....
" placed " "	....	....	504,688.00	835,847
Back fill " " "	....	....	2,582.00	1,974
Average No. of cranes working	1.6	....	2.84	....
Rate per hr. per crane, cubic yards.	132.86	101.57	62.31	47.63
" " " " mixer, " "	67.98	51.97	....	....

The masonry at Pedro Miguel included both plain and reinforced concrete; the former was composed of 1:3:6 parts of cement, sand, and stone, respectively, and the latter of 1:2.5:5 parts. The amount and unit cost of each are shown in Table 8.

TABLE NO. 8.

Concrete at Pedro Miguel Locks.

Fiscal Year	Plain Concrete		Unit Cost		Reinforced Concrete		Unit Cost		Remarks
	cu. yds.	cu. m.	cu. yd.	cu. m.	cu. yds.	cu. m.	cu. yd.	cu. m.	
1910	166,869	127,575	$6.089	$7.964	....	....	....	....	All costs are division costs including plant charge.
1911	497,802	380,583	4.704	6.153	385	294	$17.742	$23.206	
1912	134,193	102,594	5.718	7.479	48,677	37,214	8.519	11.143	
1913	39,465	30,172	6.543	8.532	18,697	14,294	9.467	12.377	
1914	1,069	817	20.557	26.888	18	13	128.735	168.385	
Total	839,398	641,741	5.248	6.864	67,777	51,815	8.865	11.595	

Grand Total 907,175 cu. yds. (693,591 cu. m.) at $5.519 per cu. yd. ($7,219 per cu. m.).

Concrete Forms.—With the exception of the collapsible steel forms used for the main and lateral culverts, all forming was of wood, as shown in detail on Plates VIII and IX. The panels were 15 feet (4.57 m.) long and 6 feet (1.82 m.) high and were bolted to the concrete with anchor bolts 2 ft. 6 in. (76.2 cm.) long, which were removed, leaving the anchor nut imbedded. The design of all forms, including many special shapes, was carefully worked out, so that they could be used from six to twelve times, as the conditions required, and some of them were transferred to the Miraflores work in good con-

dition. The steel forms were re-used at both sites a large number of times; those for the main culverts, which were 18 feet (5.48 m.) in diameter, were so constructed that, when slightly collapsed, they could be hauled ahead to a new position with winches. The average cost of forms for plain concrete was $0.524 per cubic yard ($0.685 per cu. m.), and for reinforced concrete $1.76 per cu. yd. ($2.30 per cu. m.).

CONSTRUCTION METHODS AT MIRAFLORES.

Lock Excavation.

A greater portion of the Miraflores site occupied low ground, through which the Rio Cocoli and Rio Grande flowed, and which was occasionally submerged during extreme floods. This condition necessitated diverting the rivers and protecting the site with embankments on all sides. As those parallel to the longitudinal axis, on the east and west sides, would eventually be incorporated in the back filling for the side walls, they were constructed to a proper elevation and width to accommodate the concrete handling equipment. Steam shovels began work at the north end and on the diversions in January, 1908, continuing until the completion of the excavation; the conditions as to dead ends and hauling up steep grades, as described for Pedro Miguel, prevailed in a greater degree at Miraflores, as a large percentage of the excavation was below sea level. The most perplexing problem was the method of excavating the site of the south lock, where a partly saturated alluvial deposit, about 40 feet (12.2 m.) in depth, overlay rock. This formation extended along the canal prism for about a mile and a half (2.4 km.) south from the lock and, on the whole, involved the removal of approximately 8,200,000 cubic yards (6,269,113 cu. m.) of alluvial material and 1,500,000 cubic yards (1,146,789 cu. m.) of rock. The situation is summed up as follows in the Annual Report of 1910:

> "It was manifestly impracticable to remove the earth and rock by dredging and subaqueous methods, as the requisite number of dredges, barges, drill scows and rock breakers would have called for an unwarranted expenditure and could not have been assembled and placed in commission so as to complete the work in the allotted time. A

careful study of the conditions showed that the rock could be excavated by steam shovels, in the dry, in a shorter time and at less cost than by any other method. This, however, is not true in regard to the overlying alluvial deposit, as steam shovels and other equipment were not available in sufficient number to remove it at the required rate and in addition the maintenance of tracks would be difficult and expensive in this partly saturated material''.

Under the circumstances a hydraulic excavating plant was chosen as the most expeditious means of removing the earth, part of which was pumped into the west dam at Miraflores and the remainder onto the adjacent swamp lands, which it was desired to reclaim for sanitary reasons and to enhance the future value. In an effort to advance the work, the dredge ''Sandpiper'' was towed to the site at high tide and worked while the hydraulic plant was being manufactured. The performance of the dredge was not very satisfactory in the material encountered and it was transferred to the Atlantic division. The amount and cost of excavating the lock site were as given in Table 9.

TABLE NO. 9.

Excavation at Miraflores Locks.

Fiscal Year	Dry Excavation		Unit Cost		Wet Excavation		Unit cost		Remarks
	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.	cu. yds.	cu. m.	
1909	1,120,342	856,530	$0.814	$1.065	167,888	128,355	$0.341	....	Dredge
1910	229,793	175,682	1.322	1.729	141,759	108,378	0.506	....	Dredge
1911	247,700	189,374	0.738	0.965	332,703	254,360	0.548	....	Hydraulic
1912	624,747	477,635	0.656	0.858	....	....	....	....	
1913	....	....	....	....	....	....	....	....	
Total	2,222,582	1,699,221	0.814	1.064	642,350	491,093	0.485	....	

Total excavation, 2,864,932 cu. yds. (2,190,314 cu. m.), average cost $0.740 per cu. yd. ($0.968 per c. m.).

Preparing Foundations.

As at Pedro Miguel, this was mainly hand work and consisted of leveling up and excavating for lateral culverts and other trenches below the floor level. The amount of rock excavated was 415,981 cubic yards (318,028 cu. m.) at an average cost of $1.718 per cu. yd. ($2.247 per cu. m.).

Concrete Construction.

Auxiliary Plant.—The auxiliary plant at Miraflores was composed of two 64-cubic-foot (1.81 cu. m.) mixers and from four to eight ½-cubic-yard (0.38 cu. m.) mixers, some of the latter being transferred from Pedro Miguel as work progressed. The portable mixers were moved as desired and were used for placing the lock floors, upper guide and wing walls, and other portions of the work that were inaccessible for the main plant. As at Pedro Miguel, the auxiliary mixers were utilized to a greater extent than originally intended by reason of subsequent alterations in the lock designs. The two large mixers were set up at the north end of the east storage trestle, where they could be supplied with sand and stone by gravity, from September, 1910, to May, 1911. They were then moved to a position on the east lock wall and really became an addition to the main plant, as described later. The output of these two mixers, while located under the east trestle, was transported on cars to derricks or cranes and, for a time, was placed with one of the berm cranes, which, though incomplete, was sufficiently equipped to operate the boom extending over the side wall.

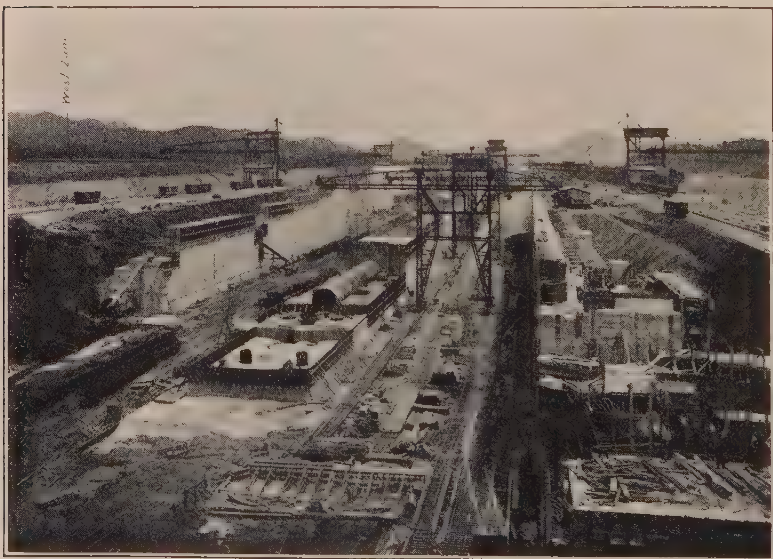


Fig. 7. Miraflores Lower Locks. Looking North from East Bank.

ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
PEDRO MIGUEL TO PANAMA BAY
PANAMA
ANCON
ANCON HILL
BALBOA
COROZAL
NAOS I.
PERICO I.
FLAMENCO I.
CULEBRA I.
PUNTA PATILLA
PACIFIC
OCEAN
Miraflores Lake
Rio Grande
Rio Cardenas
Rio Cocoli
Rio Velazquez
Camino de Velazquez
Rio Farfan
Camino
SCALE IN FEET
EXCAVATION DIAGRAM
Excess Dredging shown, due to Silting
July 1, 1907 to June 30, 1908
July 1, 1908 to June 30, 09
July 1, 1909 to June 30 1910
To be excavated

Plate I.

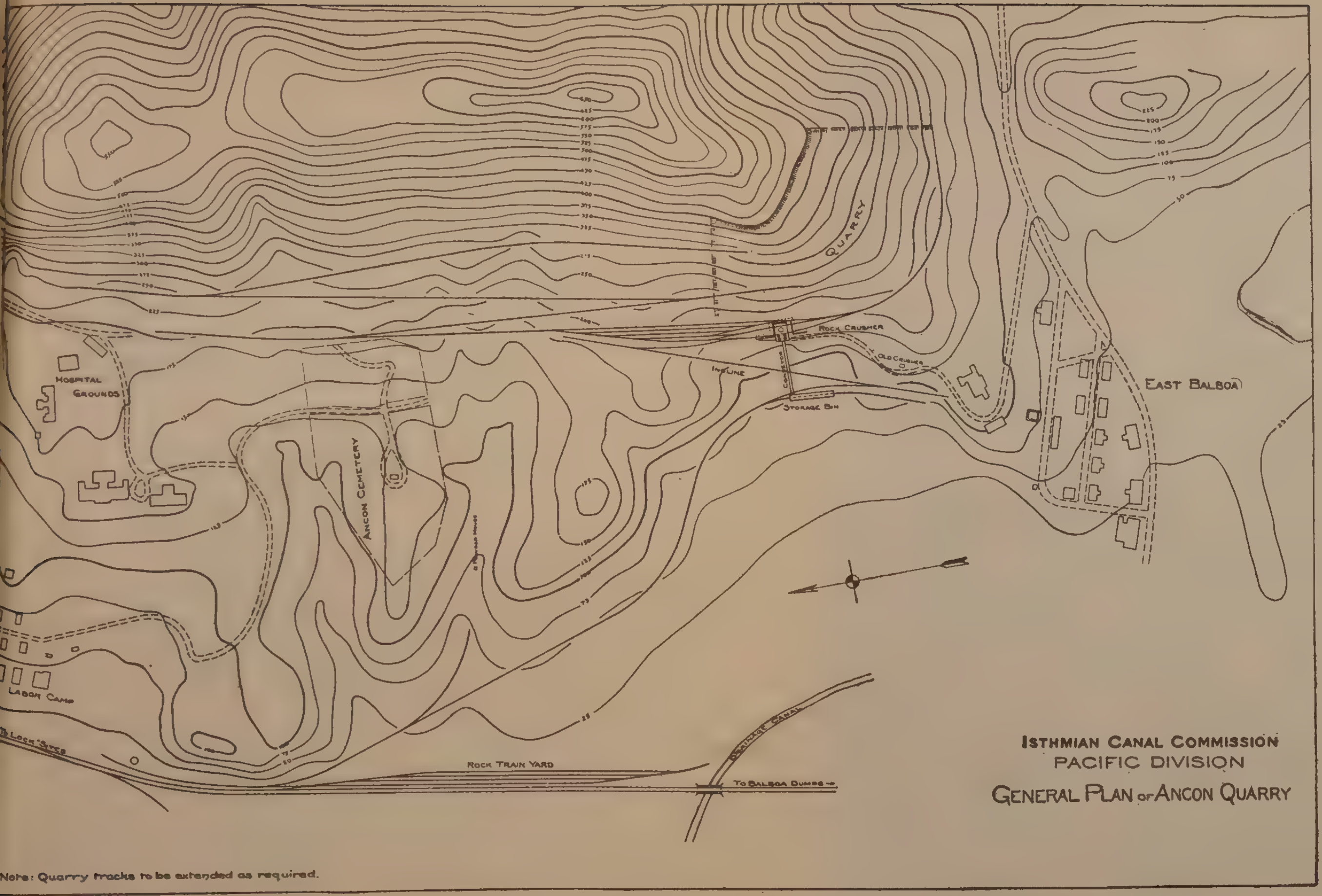
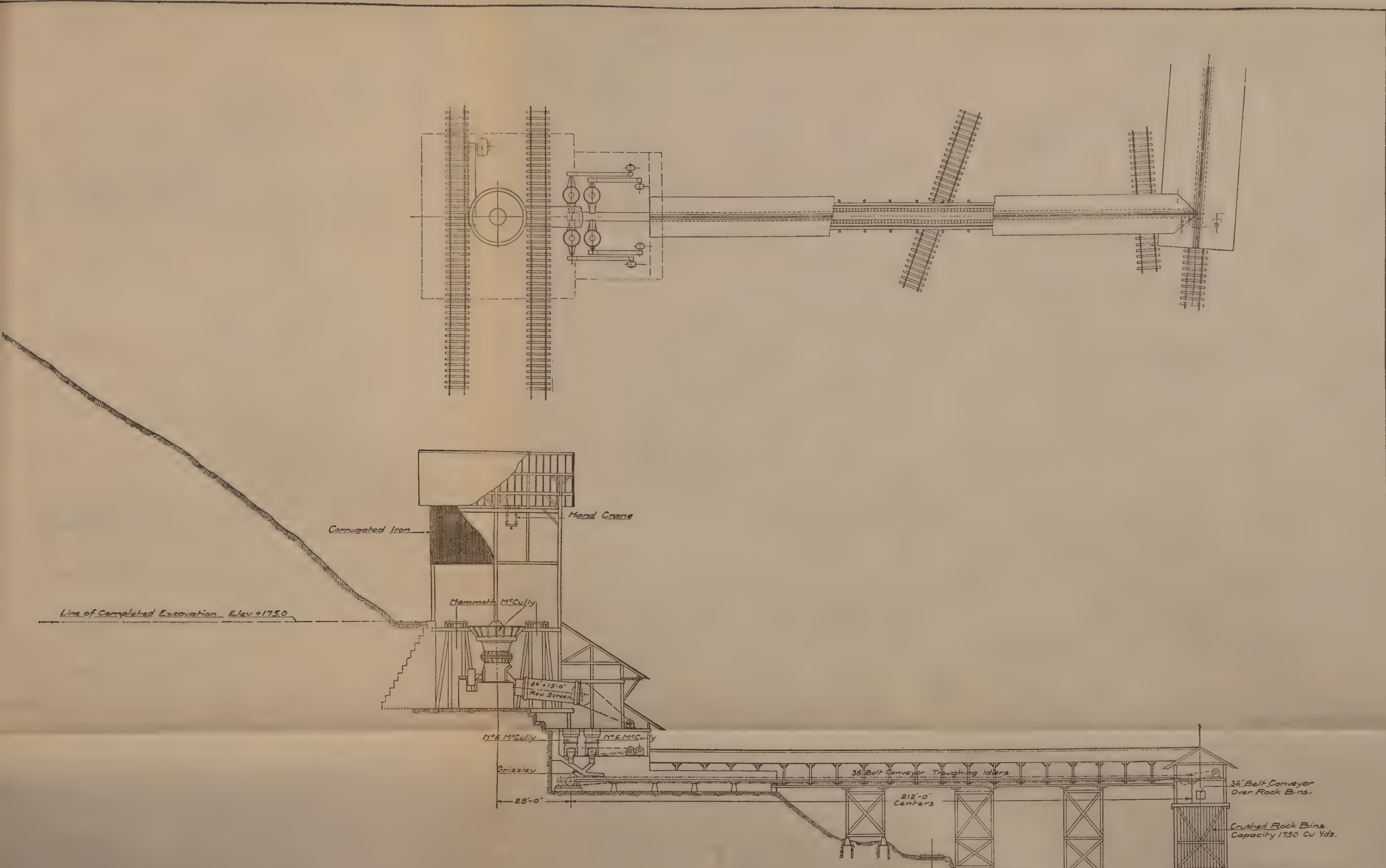
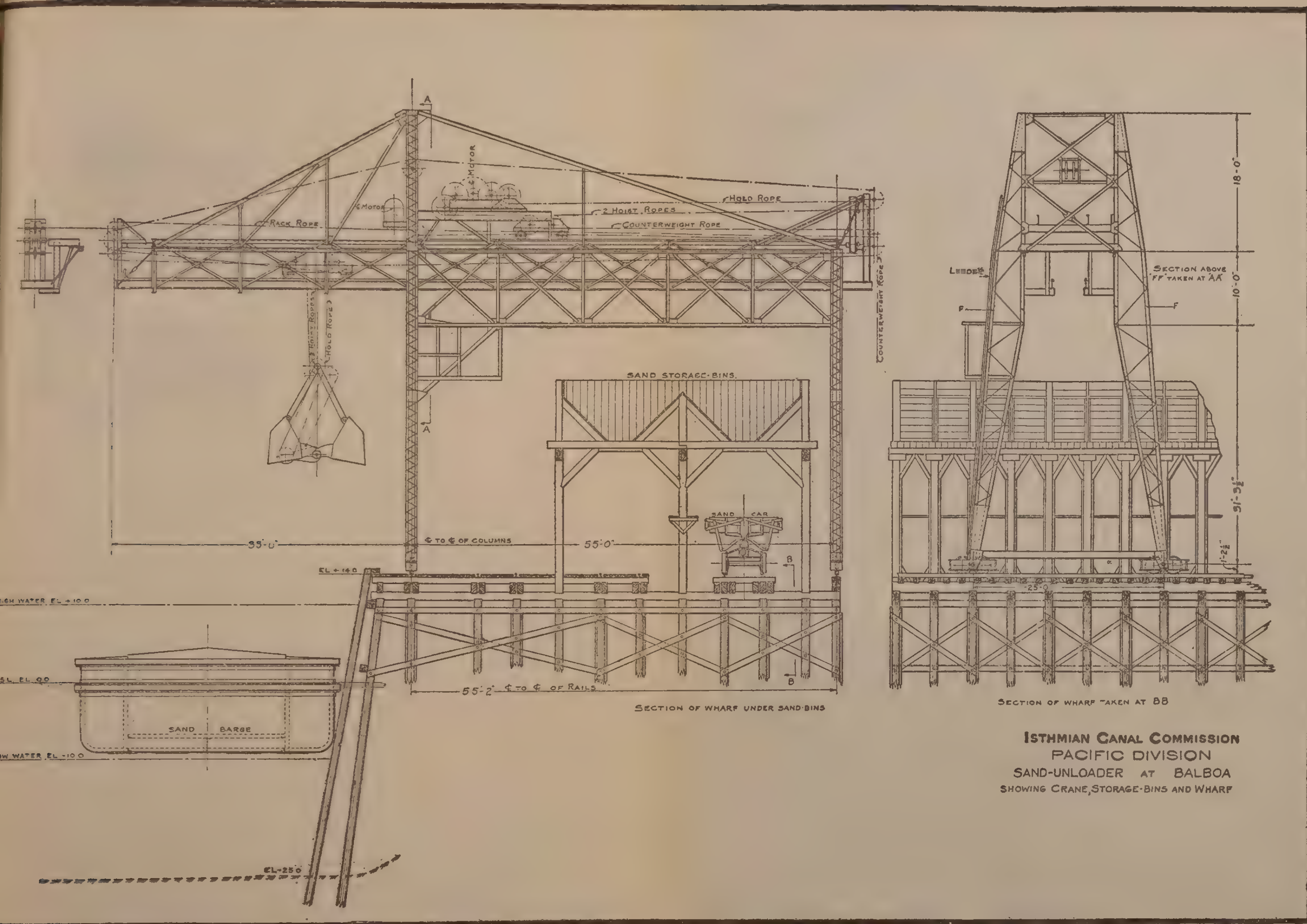

QUARRY
ROCK CRUSHER
OLD CRUSHER
INCLINE
STORAGE BIN
HOSPITAL GROUNDS
ANCON CEMETERY
EAST BALSOA
LABOR CAMP
TO LOCK SITES
ROCK TRAIN YARD
DRAINAGE CANAL
TO BALBOA DUMPS
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
GENERAL PLAN OF ANCON QUARRY
Note: Quarry tracks to be extended as required.

Plate II.


Hand Crane
Corrugated Iron
Mammoth McCully
Line of Completed Excavation Elev +175.0
84" x 15'-0" Rev. Screen
No 6 McCully
No 6 McCully
Grizzley
25'-0"
36 Belt Conveyor Troughing Idlers
212'-0" Centers
36" Belt Conveyor Over Rock Bins.
Crushed Rock Bins. Capacity 1750 Cu Yds.
Reinforced Concrete Substructure.
Elev +70.5
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
LAY OUT OF CRUSHERS & STORAGE BIN
ANCON QUARRY



Rack Rope
Motor
Motor
2 Hoist Ropes
Hold Rope
Counterweight Rope
2 Hoist Ropes
Hold Rope
Counterweight Rope
Sand Storage-Bins
Sand Car
Section above "FF" taken at "AA"
18'-0"
10'-0"
31'-3½"
1'-2½"
25'-0
35'-0"
℄ to ℄ of columns
55'-0"
EL +14.0
High Water El +10.0
L.S.L. El 0.0
Sand Barge
Low Water El -10.0
EL -25.0
55'-2" ℄ to ℄ of Rails
Section of wharf under sand-bins
Section of wharf taken at BB
Isthmian Canal Commission
Pacific Division
Sand-Unloader at Balboa
Showing Crane, Storage-Bins and Wharf

Plate IV.

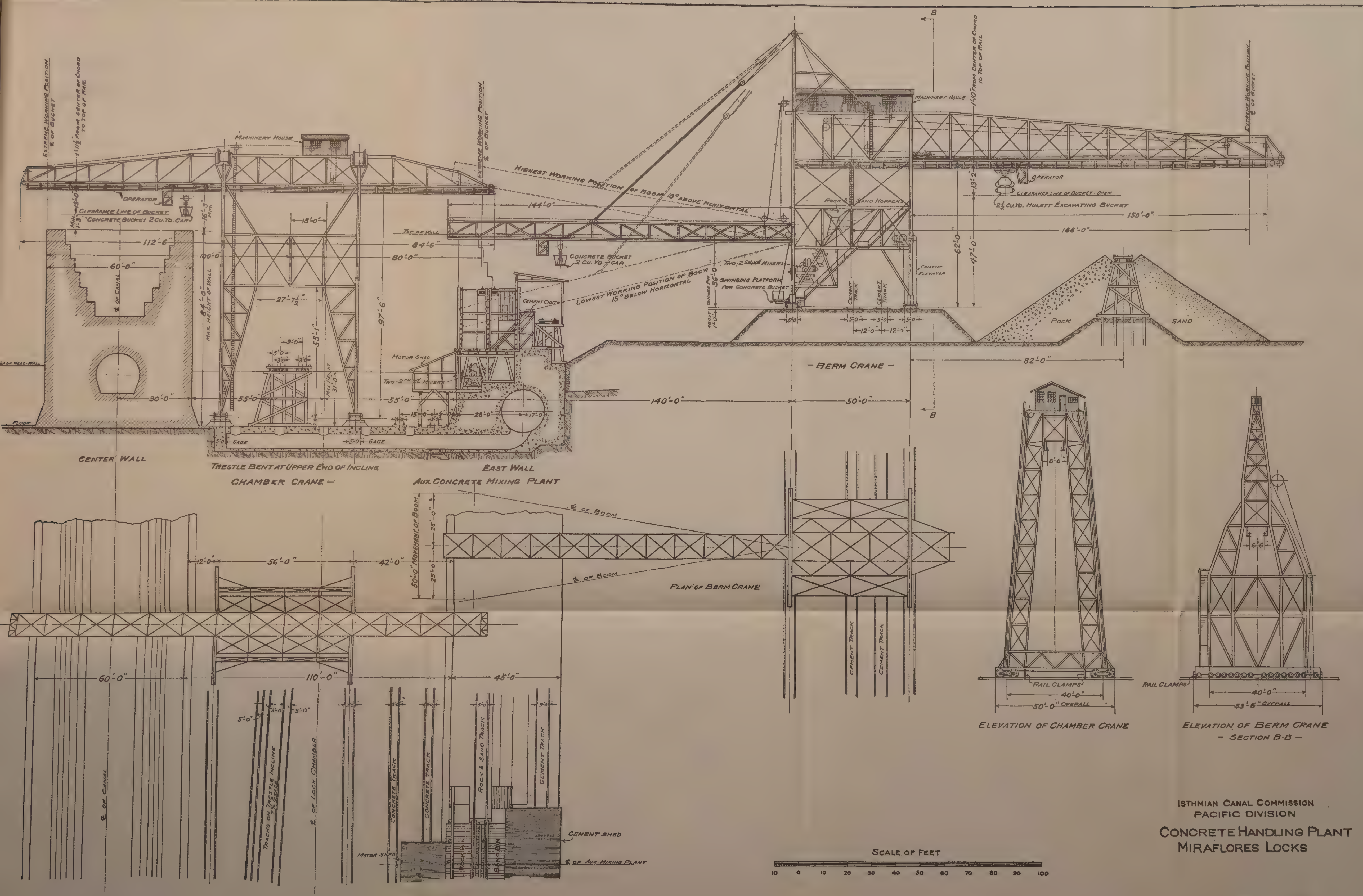
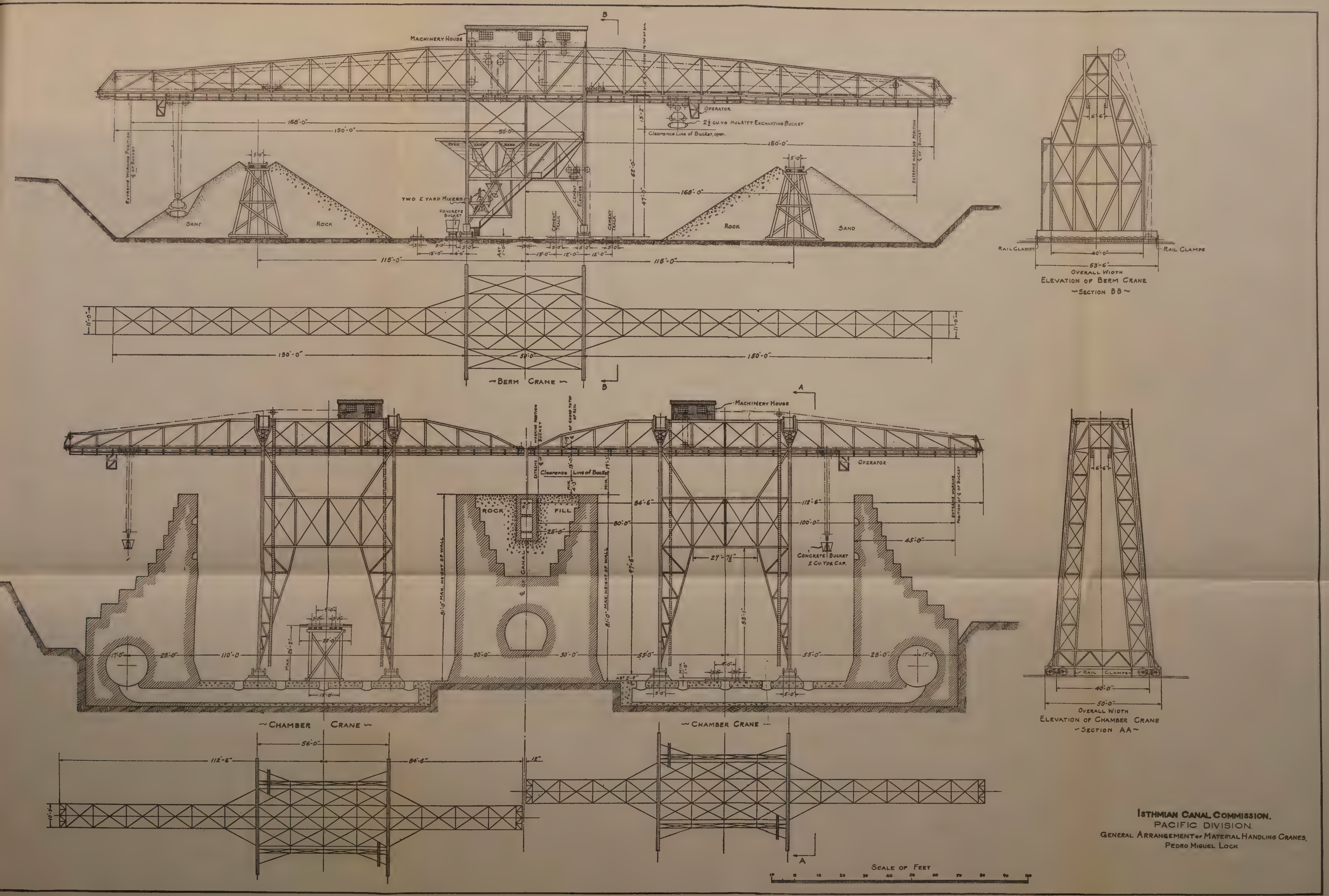

ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
CONCRETE HANDLING PLANT
MIRAFLORES LOCKS
CENTER WALL
TRESTLE BENT AT UPPER END OF INCLINE
CHAMBER CRANE
EAST WALL
AUX. CONCRETE MIXING PLANT
BERM CRANE
PLAN OF BERM CRANE
ELEVATION OF CHAMBER CRANE
ELEVATION OF BERM CRANE
- SECTION B-B -
HIGHEST WORKING POSITION OF BOOM 10° ABOVE HORIZONTAL
LOWEST WORKING POSITION OF BOOM 15° BELOW HORIZONTAL
MACHINERY HOUSE
OPERATOR
ROCK
SAND
CEMENT SHED
MOTOR SHED
RAIL CLAMPS
SCALE OF FEET

Plate V.



Machinery House
Operator
2½ Cu. Yd. Hulett Excavating Bucket
Clearance Line of Bucket, open.
Extreme Working Position ℄ of Bucket
Two 2 Yard Mixers
Concrete Bucket
Cement Track
Cement Elevator
Sand
Rock
~ Berm Crane ~
Rail Clamps
Overall Width
Elevation of Berm Crane
~ Section BB ~
Rock
Fill
Canal
Max. Height of Wall
Clearance Line of Bucket
Concrete Bucket 2 Cu. Yds. Cap.
~ Chamber Crane ~
~ Chamber Crane ~
Elevation of Chamber Crane
~ Section AA ~
Isthmian Canal Commission.
Pacific Division.
General Arrangement of Material Handling Cranes,
Pedro Miguel Lock
Scale of Feet

Plate VI.

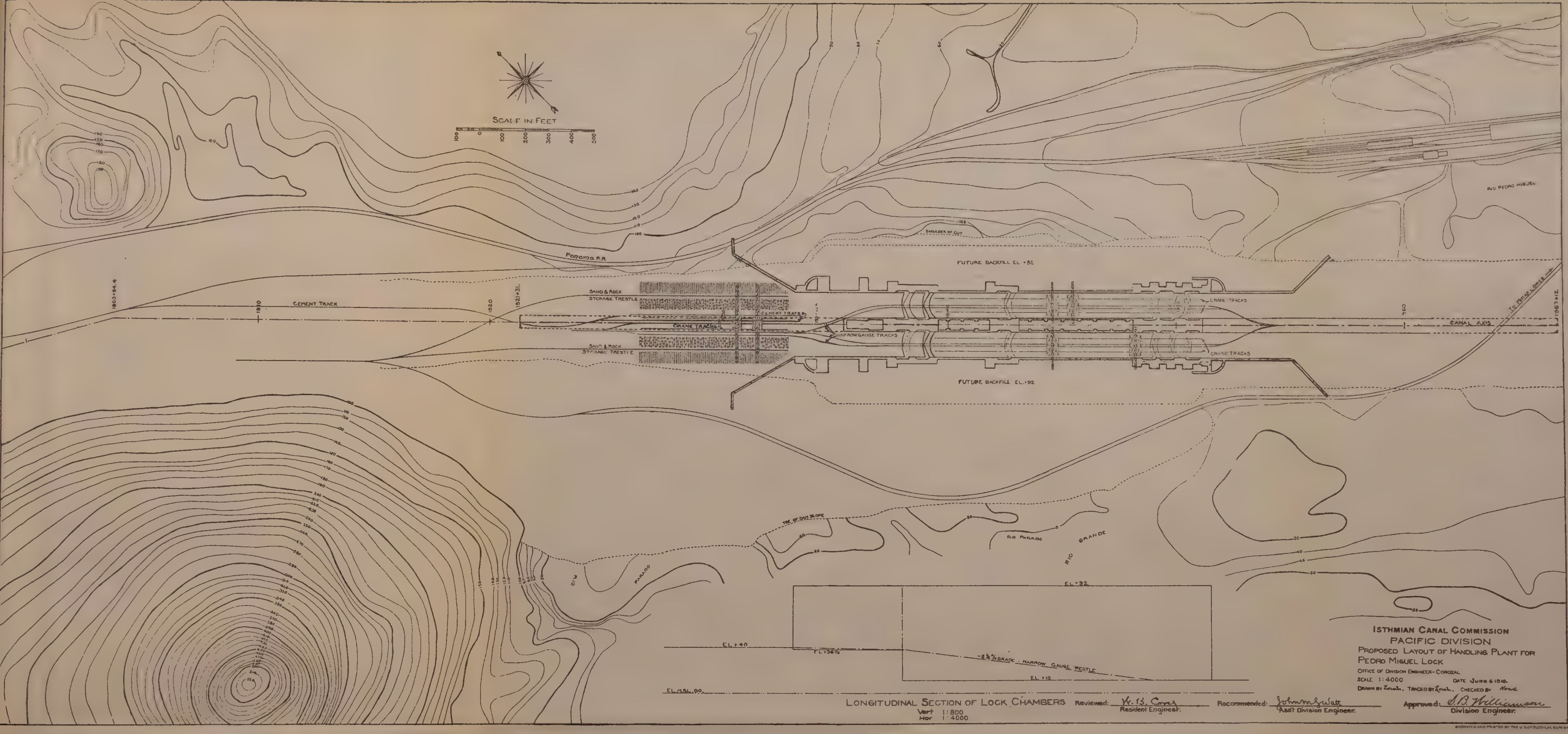

SCALE IN FEET
100 0 100 200 300 400 500
Panama R.R.
SHOULDER OF CUT
FUTURE BACKFILL EL.+92
CEMENT TRACK
SAND & ROCK STORAGE TRESTLE
CEMENT TRACKS
CRANE TRACKS
NARROW GAUGE TRACKS
CRANE TRACKS
CANAL AXIS
RIO PEDRO MIGUEL
FUTURE BACKFILL EL.+92
TOE OF DUMP SLOPE
RIO PARAISO
RIO GRANDE
EL+92
EL+40
EL+36½
-2¾% GRADE - NARROW GAUGE TRESTLE
EL+10
EL.MSL.00
LONGITUDINAL SECTION OF LOCK CHAMBERS
Vert 1:800
Hor 1:4000
Reviewed: W. B. Caves
Resident Engineer.
Recommended: John M. G. Watt
Ass't Division Engineer.
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
PROPOSED LAYOUT OF HANDLING PLANT FOR
PEDRO MIGUEL LOCK
OFFICE OF DIVISION ENGINEER-COROZAL
SCALE 1:4000
DATE JUNE 6 1910.
CHECKED BY
Approved: S. B. Williamson
Division Engineer.
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

Plate VII.

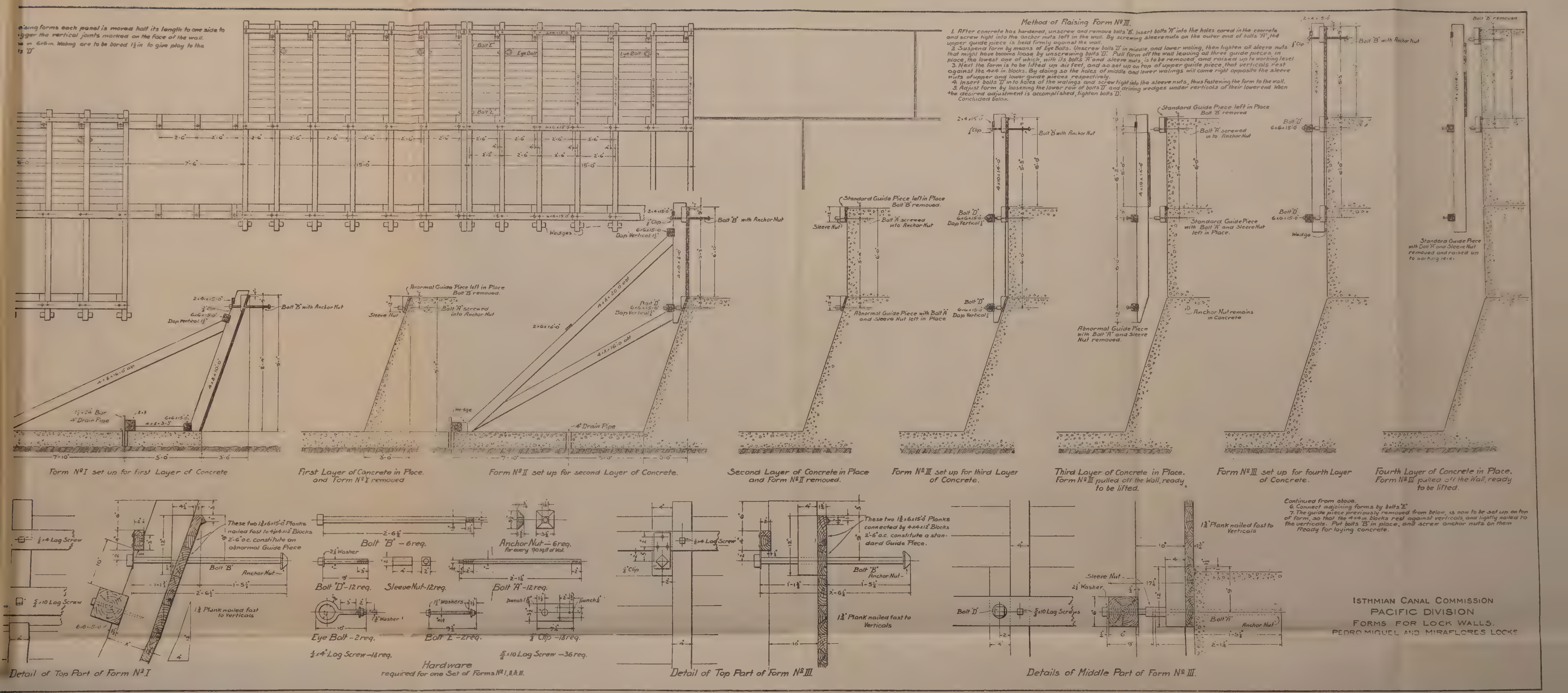
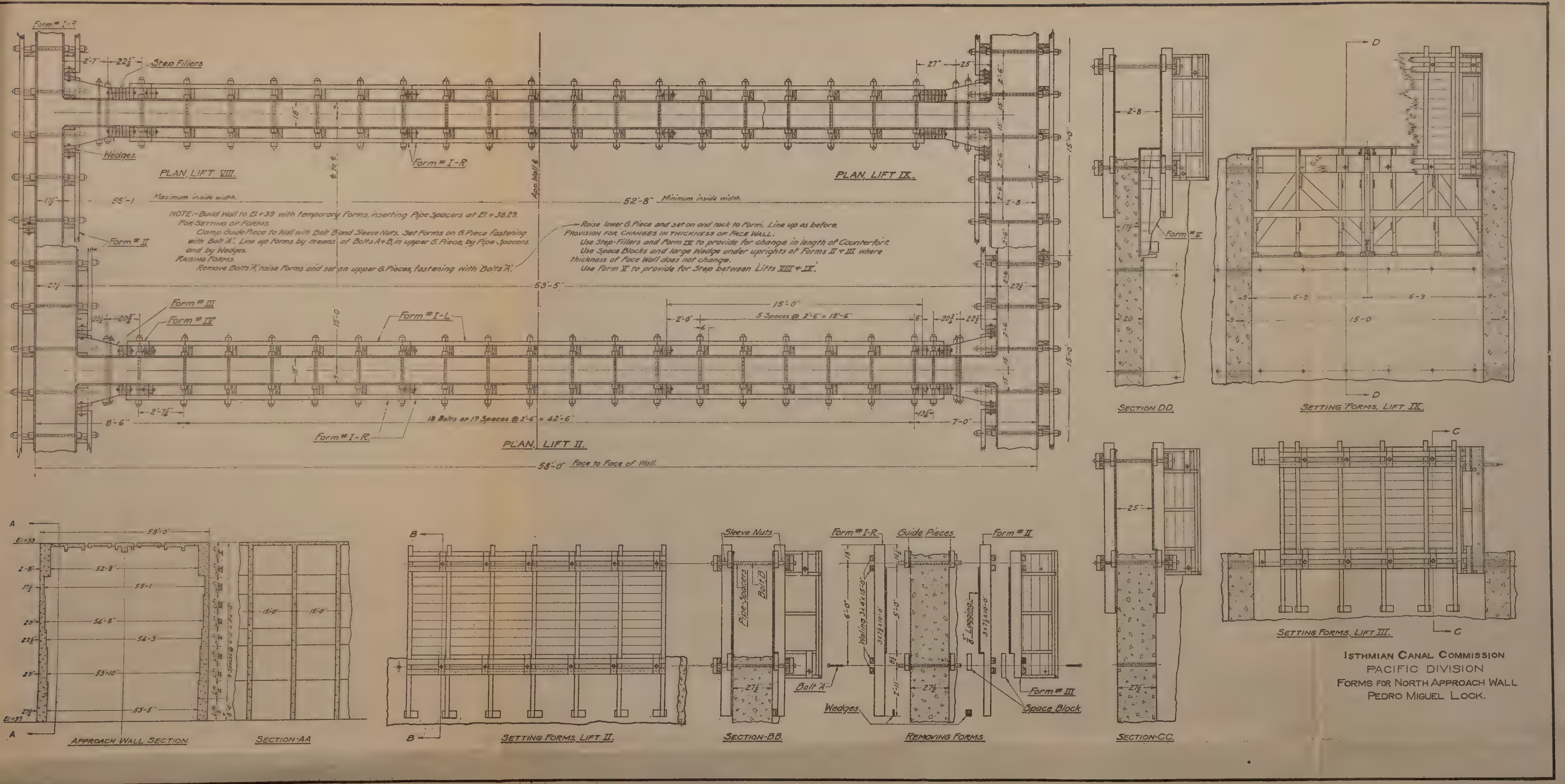

Method of Raising Form Nº III.
1. After concrete has hardened, unscrew and remove bolts "B". Insert bolts "A" into the holes cored in the concrete and screw tight into the anchor nuts left in the wall. By screwing sleeve nuts on the outer end of bolts "A", the upper guide piece is held firmly against the wall.
2. Suspend form by means of Eye Bolts. Unscrew bolts "D" in middle, and lower waling, then tighten all sleeve nuts that might have become loose by unscrewing bolts "D". Pull form off the wall leaving all three guide pieces in place, the lowest one of which, with its bolts "A" and sleeve nuts, is to be removed and raised up to working level
3. Next the form is to be lifted up six feet, and so set up on top of upper guide piece, that verticals rest against the 4x4 in. blocks. By doing so the holes of middle and lower walings will come right opposite the sleeve nuts of upper and lower guide pieces respectively.
4. Insert bolts "D" into holes of the walings and screw tight into the sleeve nuts, thus fastening the form to the wall.
5. Adjust form by loosening the lower row of bolts "D" and driving wedges under verticals of their lower end. When the desired adjustment is accomplished, tighten bolts "D".
Concluded below.
Continued from above.
6. Connect adjoining forms by bolts "E"
7. The guide piece previously removed from below, is now to be set up on top of form, so that the 4x4 in. blocks rest against verticals, and lightly nailed to the verticals. Put bolts "B" in place, and screw anchor nuts on them
Ready for laying concrete.
Form Nº I set up for first Layer of Concrete
First Layer of Concrete in Place and Form Nº I removed
Form Nº II set up for second Layer of Concrete.
Second Layer of Concrete in Place and Form Nº II removed.
Form Nº III set up for third Layer of Concrete.
Third Layer of Concrete in Place. Form Nº III pulled off the Wall, ready to be lifted.
Form Nº III set up for fourth Layer of Concrete.
Fourth Layer of Concrete in Place. Form Nº III pulled off the Wall, ready to be lifted.
Standard Guide Piece left in Place Bolt "B" removed
Bolt "A" screwed into Anchor Nut
Abnormal Guide Piece left in Place Bolt "B" removed.
Abnormal Guide Piece with Bolt "A" and Sleeve Nut left in Place
Anchor Nut remains in Concrete
Bolt "B" with Anchor Nut
4" Drain Pipe
Wedge
Detail of Top Part of Form Nº I
These two 1½x6x15'-0" Planks nailed fast to 4x4x12 Blocks 2'-6" o.c. constitute an abnormal Guide Piece
1¾" Plank nailed fast to Verticals
Bolt "B" - 6 req.
Anchor Nut - 6 req.
Bolt "D" - 12 req.
Sleeve Nut - 12 req.
Bolt "A" - 12 req.
Eye Bolt - 2 req.
Bolt "E" - 2 req.
¼" Clip - 18 req.
½x4" Log Screw - 18 req.
⅝x10 Log Screw - 36 req.
Hardware required for one Set of Forms Nº I, II & III.
Detail of Top Part of Form Nº III
These two 1½x6x15'-0" Planks connected by 4x4x12" Blocks 2'-6" o.c. constitute a standard Guide Piece.
Details of Middle Part of Form Nº III.
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
FORMS FOR LOCK WALLS.
PEDRO MIGUEL AND MIRAFLORES LOCKS

Plate VIII.



PLAN, LIFT VIII.
PLAN, LIFT IX.
PLAN, LIFT II.
Step Fillers
Wedges.
Form # I-R
Form # II
Form # III
Form # IV
Form # I-L
Maximum inside width.
52'-8" Minimum inside width.
NOTE:-Build Wall to El.+39 with temporary Forms, inserting Pipe Spacers at El.+38.29.
FOR SETTING OF FORMS.
Clamp Guide Piece to Wall with Bolt B and Sleeve Nuts. Set Forms on G.Piece fastening with Bolt A. Line up Forms by means of Bolts A+B, in upper G.Piece, by Pipe Spacers and by Wedges.
RAISING FORMS.
Remove Bolts A, raise Forms and set on upper G.Pieces, fastening with Bolts A.
Raise lower G.Piece and set on and tack to Form. Line up as before.
PROVISION FOR CHANGES IN THICKNESS OF FACE WALL.
Use Step-Fillers and Form IV to provide for change in length of Counterfort.
Use Space Blocks and large Wedge under uprights of Forms II + III where thickness of Face Wall does not change.
Use Form V to provide for Step between Lifts VIII + IX.
5 Spaces @ 2'-6" = 12'-6"
18 Bolts or 17 Spaces @ 2'-6" = 42'-6"
58'-0" Face to Face of Wall.
Form # V
SECTION DD.
SETTING FORMS, LIFT IX.
SECTION CC.
SETTING FORMS, LIFT III.
APPROACH WALL SECTION.
SECTION-AA
SETTING FORMS, LIFT II.
Sleeve Nuts
Pipe-Spacers
Bolt B
Bolt A
SECTION-BB.
Guide Pieces
Waling
Legging
Wedges
Space Block
REMOVING FORMS
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
FORMS FOR NORTH APPROACH WALL
PEDRO MIGUEL LOCK.

Plate IX.

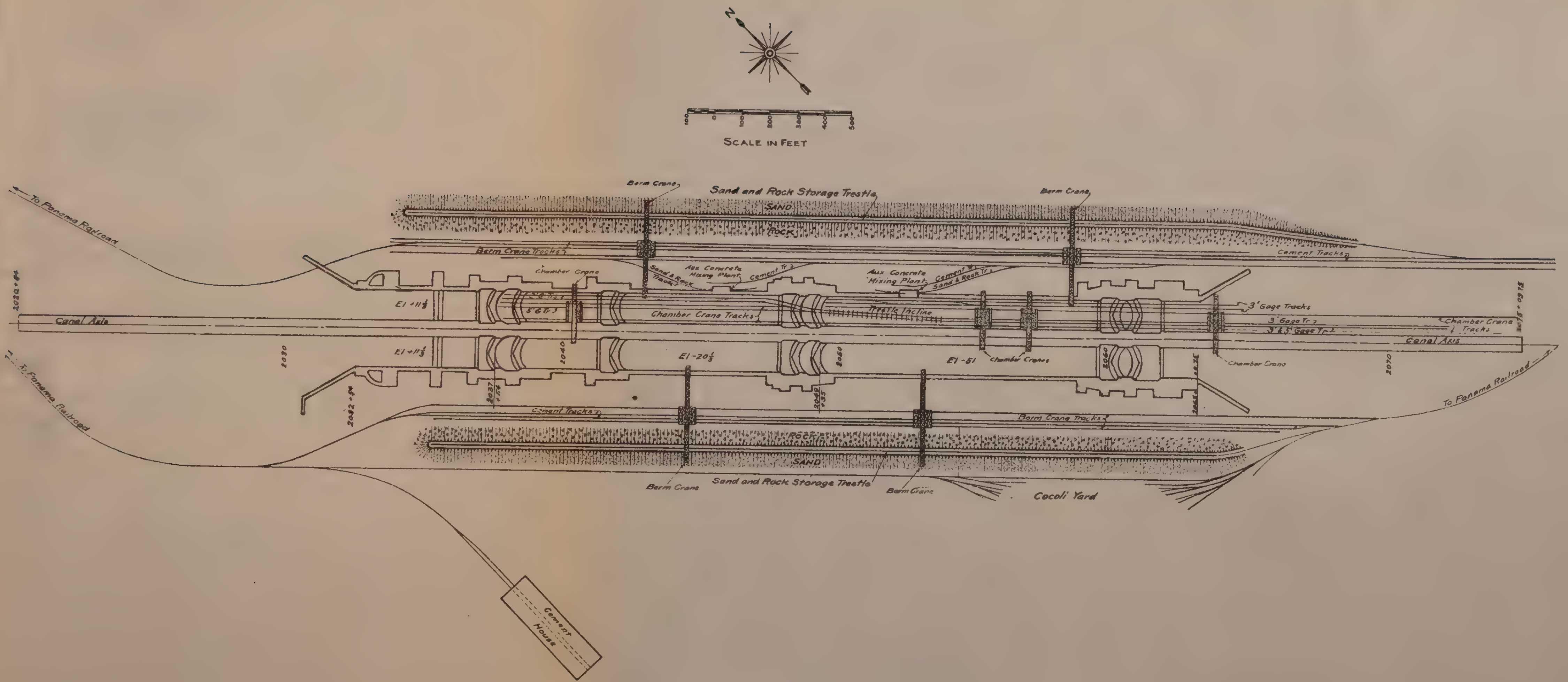
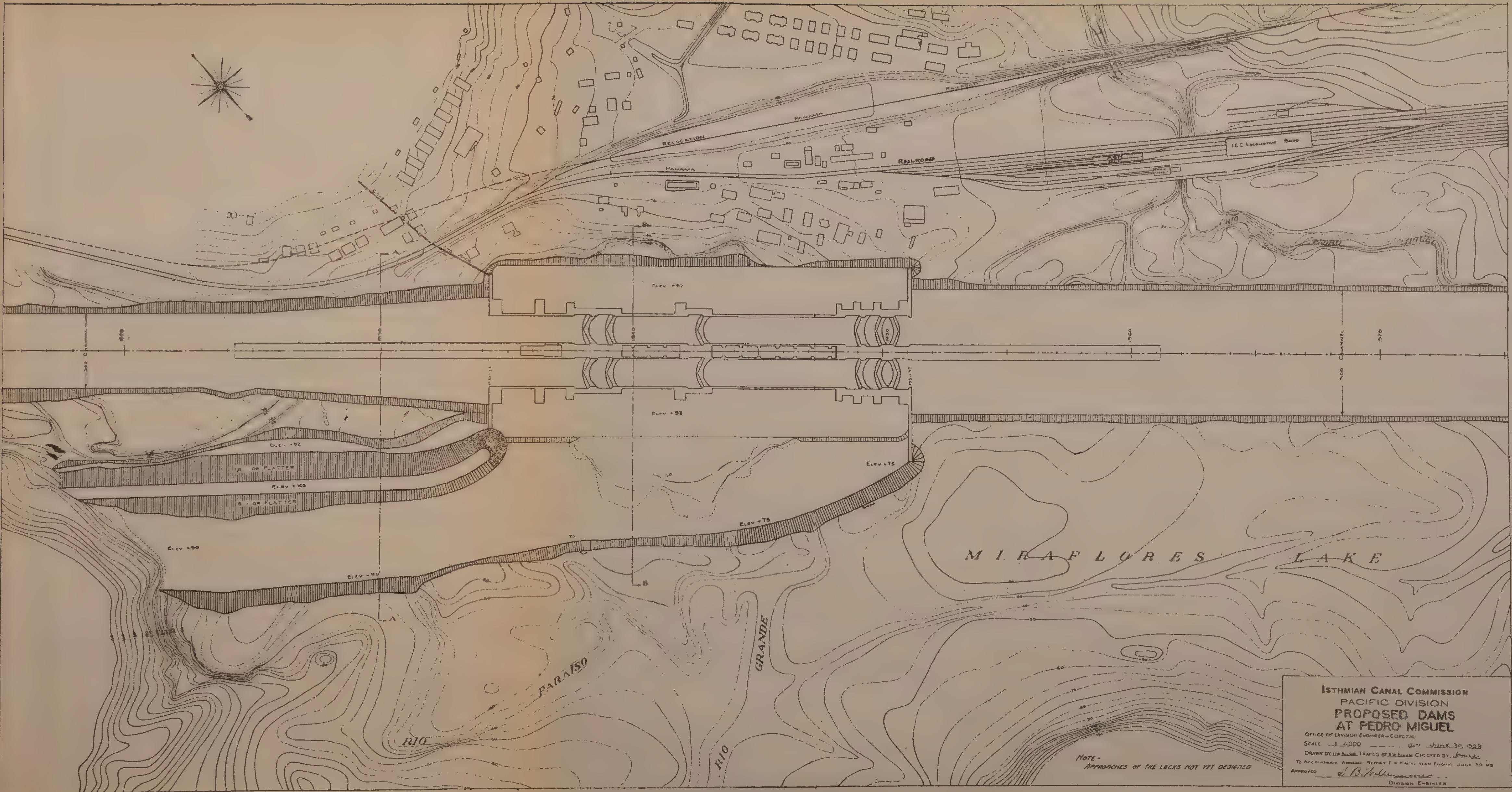


Plate X. Layout of Concrete Handling Plant at Miraflores Locks.



ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
PROPOSED DAMS
AT PEDRO MIGUEL
OFFICE OF DIVISION ENGINEER—COROZAL
SCALE 1:4000
DATE JUNE 30, 1909
DIVISION ENGINEER
APPROVED
NOTE—
APPROACHES OF THE LOCKS NOT YET DESIGNED
MIRAFLORES LAKE
RIO PARAISO
RIO GRANDE
RIO PEDRO MIGUEL
PANAMA RAILROAD
PANAMA RELOCATION
PANAMA RAILROAD
I.C.C. Locomotive Shed
ELEV +92
ELEV +92
ELEV +92
ELEV +103
ELEV +75
ELEV +75
ELEV +90
ELEV +90
300 CHANNEL
500 CHANNEL
1820
1830
1840
1850
1960
1970

Plate XI A.

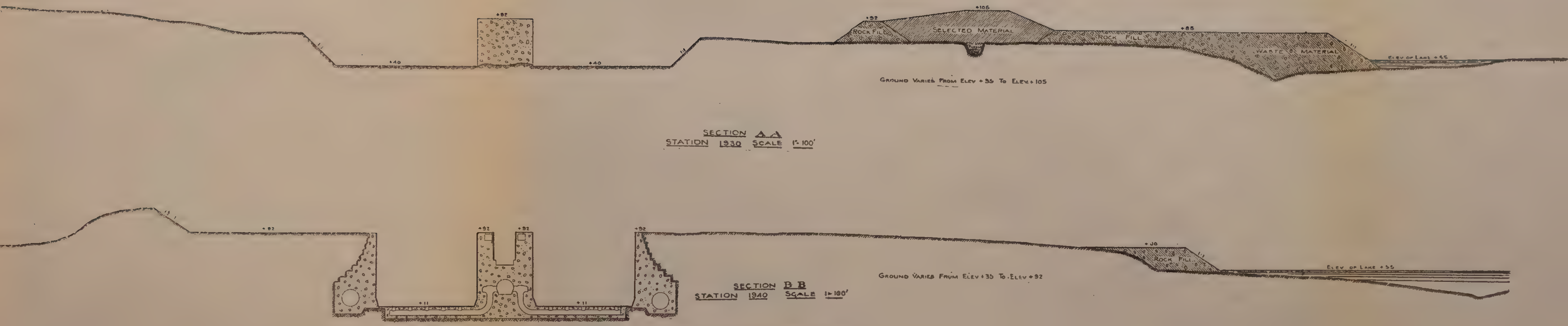


Plate XI B. Sections of Pedro Miguel Dams.

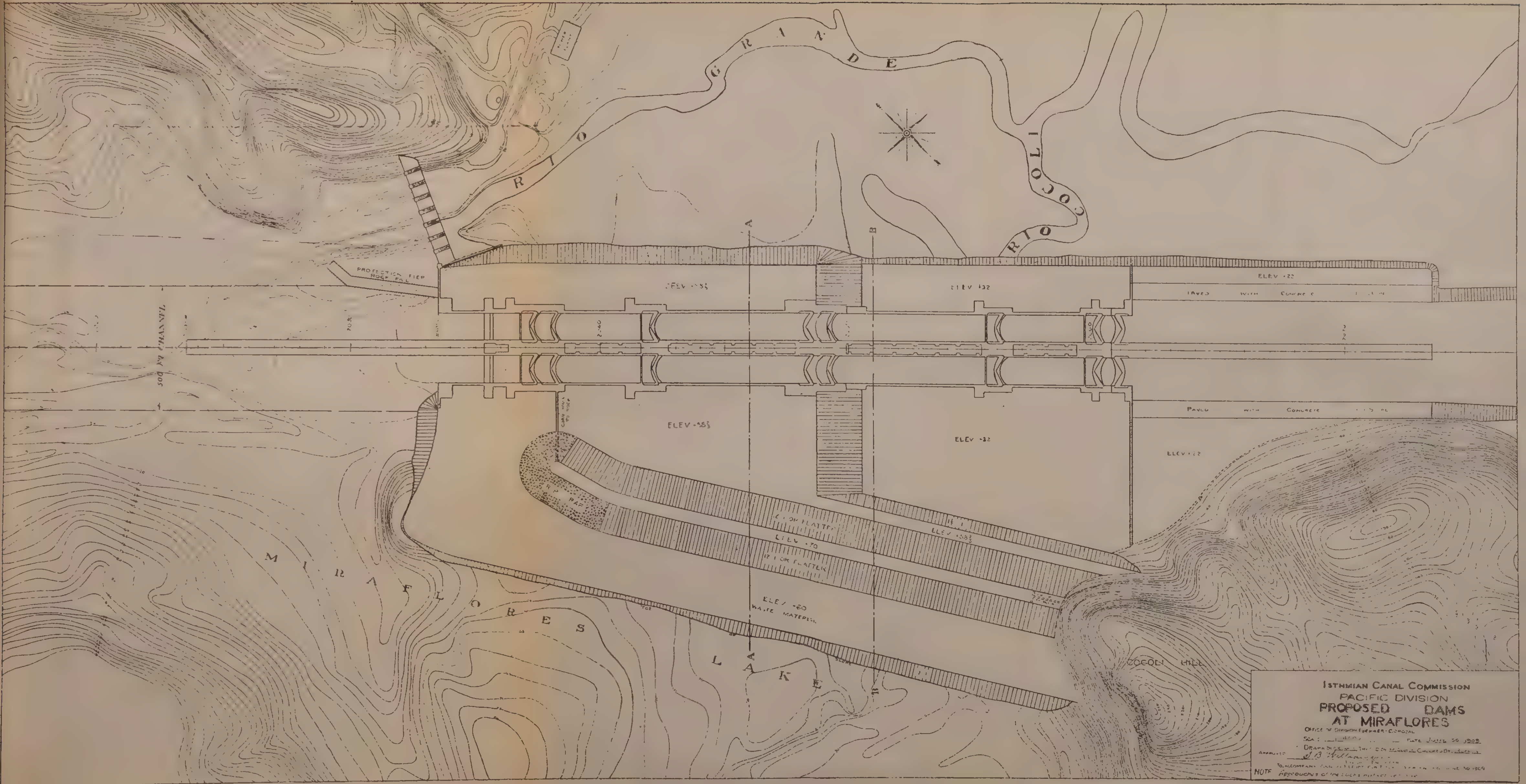
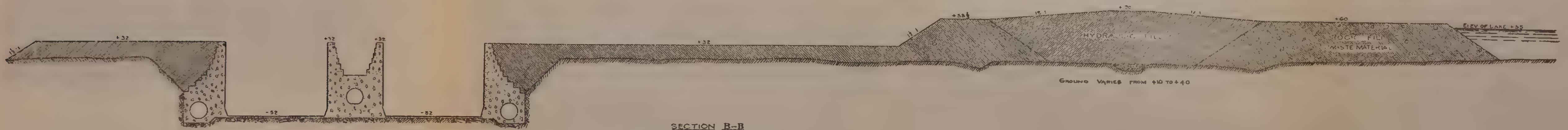

RIO GRANDE
RIO COCOLI
PROTECTION PIER ROCK FILL
500 FT CHANNEL
ELEV +55
ELEV +32
ELEV +22
ELEV +70
ELEV +60
WASTE MATERIAL
MIRAFLORES LAKE
COCOLI HILL
ISTHMIAN CANAL COMMISSION
PACIFIC DIVISION
PROPOSED DAMS
AT MIRAFLORES
OFFICE OF DIVISION ENGINEER - COROZAL
NOTE

Plate XII A.

SECTION A-A
STATION 2046 SCALE 1"=100'



SECTION B-B
STATION 2051 SCALE 1"=100'

Plate XII B. Sections of Miraflores Dams.

Main Plant.—The disposition of the units of the main plant at Miraflores is shown on Plates V and X and Figs. 8 and 9. Two berm cranes were placed back of each side wall, where they could be used for both mixing and placing; storage trestles were set up in rear of the cranes, the height of the trestles being such as to secure ample storage and a means of backfilling the higher locks without "lifting track" after the walls were finished and the trestles no longer required for storage.

Fig. 8. Miraflores Upper Locks. Berm Cranes and Storage Trestles.

The storage provided was 208,000 cubic yards of rock (159,021 cu. m.) and 180,000 cubic yards (137,615 cu. m.) of sand.

The four berm cranes, fully equipped, were used at Miraflores. They conveyed the aggregates from storage, mixed and placed concrete for the side walls and, when these were practically completed, they delivered concrete through chutes to trains for transportation to the center and guide walls. The chamber cranes were erected in the east locks, two in the upper and two in the lower, and were served by a battery of two 64-cubic-foot (1.81 cu. m.) mixers located in a niche left

for the purpose in the east wall of the upper lock. When the masonry of the upper locks was practically finished, one of the chamber cranes was lowered into the lower chamber by means of cribbing and hydraulic jacks, and the mixer battery moved from the upper wall to a corresponding position in the east wall of the lower lock. The final disposition of the chamber cranes left one in the upper chamber, for finishing the concrete and back-filling the middle wall, and three in the lower

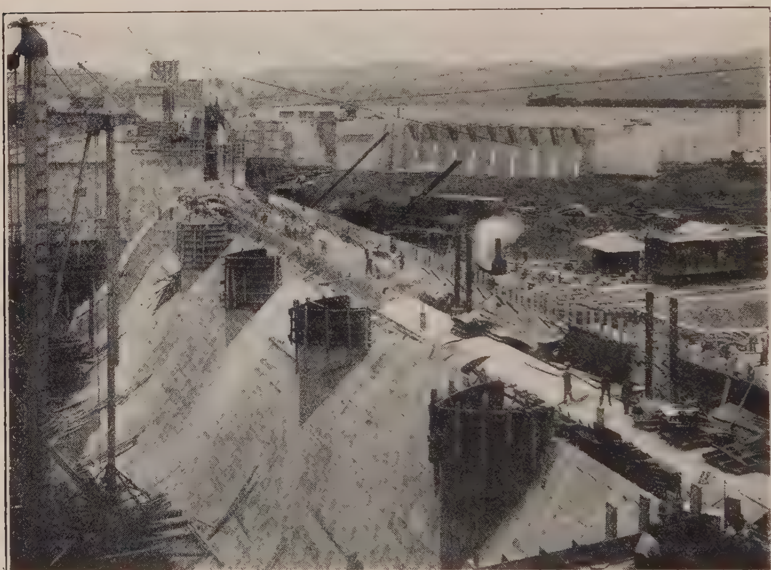


Fig. 9. Miraflores Spillway Dam.

one, for placing concrete in the lower locks and guide wall and for back-filling. Concrete was transported by the narrow-gauge railway, which had been transferred from Pedro Miguel and laid on the floors of the east chamber. The concrete in the locks proper was completed on May 17th, 1913, but the chamber cranes continued in operation for back-filling, while cranes E and F were kept in commission to supply concrete for the spillway as described later. The time of operating the several units prior to June 30th, 1913, was as in Table 10.

TABLE NO. 10.

Working Time of Cranes at Miraflores.

Designation	Working Time Began	Working Time Stopped	Working Days
Crane E	Oct. 28, 1911	June 30, 1913	513
" F	Mch. 22, 1911	June 30, 1913	698
" G	July 25, 1911	May 14, 1913	552
" H	Apr. 7, 1911	May 14, 1913	642
" 1	Mch. 26, 1912	June 30, 1913	390
" 2	July 13, 1911	June 30, 1913	606
" 3	Feb. 15, 1912	June 30, 1913	423
" 4	Aug. 3, 1911	June 30, 1913	590

It will be noted that while "Crane F" began work on March 22nd, 1911, the entire plant did not get into action until March 26th, 1912, and worked as a whole to May 14th, 1913. The performance prior to June 30th, 1913, was as given in Table 11.

TABLE NO. 11.

Performance of Cranes at Miraflores.

	Berm Cranes		Chamber Cranes	
	cu. yd.	cu. m.	cu. yd.	cu. m.
Number of crane days	2,405.00		2,009.00	
" " " hours	11,029.09		10,168.25	
" " mixer hours	20,568.69			
Concrete mixed, cubic yards	785,339.00	600,412.00		
" placed " "	615,477.00	470,548.00	452,655.00	346,066.00
Back fill " " "			99,701.00	76,224.00
Average number of cranes working	3.45		3.30	
Rate per hour per crane, cubic yards	71.38	54.51	54.32	41.52
" " " " mixer " "	38.20	29.20		

The concrete was mixed in the same proportions as given for Pedro Miguel and the amount and unit costs are shown in Table 12.

TABLE NO. 12.

Concrete at Miraflores Locks.

Fiscal Year	Plain Concrete		Unit Cost		Reinforced Concrete		Unit Cost		Remarks
	cu. yds.	cu. m.	cu. yd.	cu. m.	cu. yds.	cu. m.	cu. yd.	cu. m.	
1910	1,630	1,246	$7.392	$9.668					Unit division costs includ- ing plant charge.
1911	272,933	208,664	4.683	6.125					
1912	729,096	557,413	4.587	5.999	22,444	17,159	$10.639	$13.915	
1913	402,607	307,803	5.027	6.575	48,185	36,839	10.802	14.129	
1914	2,218	1,696	20.480	26.787	626	478	21.309	27.872	
Total	1,408,484	1,076,822	4.759	6.224	71,255	54,476	10.843	14.182	

Grand Total 1,479,739 cu. yds. (1,131,298 cu. m.) at $5.052 per cu. yd. ($6.608 per cu. m.)

DAMS AND REGULATING WORKS.

West Dam at Pedro Miguel.

This is an earth dam composed of selected earth placed between toes consisting largely of rock. As is seen from Plate XI, it is of generous proportions. This is due to the fact that the materials used were obtained from the prism excavation and otherwise would have been wasted elsewhere. In short the dam is simply a waste dump, of which a certain portion was selected, dumped from cars in thin layers, and thoroughly wet down and compacted. The foundation was investigated by means of drills and test pits, which showed it to be impervious except for a distance of about 300 feet (91.4 m.) where the original bed of the Rio Grande crossed the site. A layer of gravel about 4 feet (1.2 m.) thick was found in this area resting upon the rock. This was removed for a width of about 20 feet (6.1 m.) along the axis of the dam and replaced with a puddled core and the entire site was cleared, grubbed, and plowed before filling began. The top of the toe on the water side was carried to reference 92 feet (28.0 m.), while the crest is 107 feet (32.6 m.), the high-water line is 87 feet (26.52 m.) and the maximum head against the dam is 47 feet (14.32 m.). The completed dam contains 699,518 cubic yards (534,800 cu. m.) and the average cost was $0.45 per cubic yard ($0.59 per cu. m.).

East Dam at Pedro Miguel.

Excepting in a cut through which the Panama Railroad passed, the surface of the ground to the east of the lock is well above the water level. To prevent seepage, however, a concrete core wall, founded on rock, was built from the lock wall to a hill immediately east of the site. The wall contains 1567 cubic yards (1198 cu. m.) of concrete, which cost $5.005 per cubic yard ($6.55 per cu. m.).

West Dam at Miraflores.

As may be seen on Plate XII, this dam extends from the upper lock gate abutment to Cocoli Hill, and is almost parallel with the locks. A shorter dam could have been built from the same point on the lock to the hills directly west, to retain Miraflores Lake; but, as the Cocoli River flowed across the

lock site, a second dam would have been required to protect the locks, and a spillway provided for the overflow of the Cocoli. It was for this reason more economical to locate the dam as shown, and incidentally turn the waters of the Cocoli into the canal system. The dam consists of a hydraulic fill sustained by two toes composed of a mixture of earth and rock, and, as at Pedro Miguel, the dam greatly exceeds the dimensions required to resist the water pressure, being built of material from the canal excavation that would otherwise be wasted. The foundation is compact and impervious, except in the bed of the Cocoli, where a trench 20 feet wide (6.1 m.) was excavated to rock and filled with puddle. A ditch of the same width and about 12 feet (3.6 m.) deep was excavated for the remaining length of the site, to insure a bonding of the natural soil and filling. The toes were filled from dump cars and kept about 10 feet (3.0 m.) above the hydraulic filling, which was pumped into the space between them by means of the dredging pumps of the hydraulic excavating plant and 20-inch (50.8 cm.) relay pumps, the lift averaging about 70 feet (21.3 m.). In May, 1911, the spillway for the surplus water from the hydraulic filling gave way through undercutting at the outer toe, and a large amount of water escaped, carrying with it about 36,000 cubic yards (27,523 cu. m.) of useful filling; unfortunately a large part of the outflow ran into the lock pit before it could be diverted, and interrupted the work for several days. Aside from several slides, which interfered with the work in their immediate vicinity, this was the only accident of any magnitude that occurred during the construction of the locks and dams. The hydraulic filling was discontinued when it reached the lake level, reference 55 feet (16.76 m.), and an attempt made to cover it with dry filling dumped from the toes. This was finally accomplished after experiencing many difficulties, such as settlements of the dry filling, which carried the tracks away, and the lifting up of the soft material from the lateral pressure; the surface of the latter rose as much as eight feet (2.4 m.) in places, and it became necessary to open a drainage channel in the west toe and permit the top silt to run off. At the junction of the dam with Cocoli Hill and the lock wall, concrete core walls extended well into the filling. The com-

pleted dam contains 1,758,423 cubic yards (1,344,360 cu. m.) of dry filling, which cost $0.458 per cubic yard ($0.599 per cu. m.) and 625,048 cubic yards (477,886 cu. m.) of hydraulic fill costing $0.085 per cu. yd. ($0.111 per cu. m.); making a total of 2,383,471 cu. yds. (1,822,246 cu. m.) at an average cost of $0.379 per cu. yd. ($0.495 per cu. m.).

East Dam at Miraflores.

The east dam is of concrete and is provided with regulating gates. Its construction was postponed, I might say, until the last minute, as it was necessary, for the protection of the lock work, to permit the Rio Grande to flow through the site. Moreover, the tracks of the Panama Railroad and of the Central division occupied the eastern portion, and could not be removed before March, 1913, without interfering with the disposal of spoil from the south end of Culebra Cut. Still another part of the site, near the west end, covered a pit excavated by the French for a lock, which had become filled with silt from the overflow of the Rio Grande. Beginning in September, 1912, a large portion of the silt was removed with a hydraulic monitor and pump, and about one-fourth of the dam site was inclosed, and excavation for foundations begun by hand within the enclosure; the material being loaded into skips and removed with derricks. When the tracks at the east end had been removed and the river confined, steam shovels were employed for excavating the remainder of the site and the basin below to grade. When the general grade had been reached, hand work was again resorted to for cleaning up, removing loose rock, and sinking the trench under the upstream toe. To facilitate the removal of excavated material and the placing of concrete, a trestle was erected immediately above and parallel to the upstream face of the dam, with a spur connecting to the railroad line at the east end. From the trestle, locomotive cranes handled excavated and other materials and placed concrete, delivered to them on cars from several stationary mixing plants. Along the downstream face a battery of derricks was installed for placing concrete mixed by one of the berm cranes, located on the east side of the lock, which had been kept in commission for this particular purpose. The berm crane and derricks were connected by narrow-gauge tracks and the concrete transported over these with the

equipment that had been employed in the construction of the locks.

The conditions necessitated several diversions of the river, the final one being made when a portion of the concrete had been brought to the proper height to pass the flow through an opening, left in the same until the work was sufficiently complete to make the closure. The excavation for the dam and basin amounted to 242,399 cu. yds. (185,320 cu. m.) and cost $1.25 per cu. yd. ($1.635 per cu. m.) and the amount of concrete placed was 74,254 cu. yds. (56,769 cu. m.), which cost $6.216 per cu. yd. ($8.13 per cu. m.).

SPECIAL FEATURES.

Concrete Barges.

Three reinforced concrete barges were constructed and used as supports for the 20-inch (50.8 cm.) centrifugals and their motors, which were employed to discharge the material excavated by the hydraulic monitors. The original idea was that, as these pumps were to be moved from time to time, it would be more economical to provide supports that could be floated into position than to dismantle and reassemble the pumping units. While it was a simple matter to flood the pit sufficiently to move the barges, it proved impossible to maintain a pool around each and keep them afloat while working. In settling on the bottom they were injured by boulders and sunken logs, so that this method was abandoned and concrete foundations with suction wells were prepared at each position thereafter. These barges stood some very rough usage, and, while they were a failure for the purpose for which they were constructed, this is not due, in the opinion of the writer, to their being made of concrete, as barges of any other material would also have been similarly injured under the circumstances.

Lock Guide Walls.

The guide walls were 1200 feet (365.8 m.) long each, and were extensions of the center walls of the locks. In constructing these, the feature that differed materially from the remainder of the work was the foundations of the upper guide wall at Miraflores. Under this wall the rock dropped off suddenly to a depth of 60 feet (18.2 m.) and greater below the

bottom of the canal, and there was no material suitable for a foundation within 30 feet (9.1 m.) of the surface. The wall was, therefore, supported by concrete caissons sunk to a secure foundation, which was usually found at about 35 feet (10.7 m.) below the surface. The caissons consisted of reinforced-concrete shells 7.5 feet (2.28 m.) in diameter and 8 inches (203.2 mm.) thick, made in sections 6 feet (1.82 m.) long, which

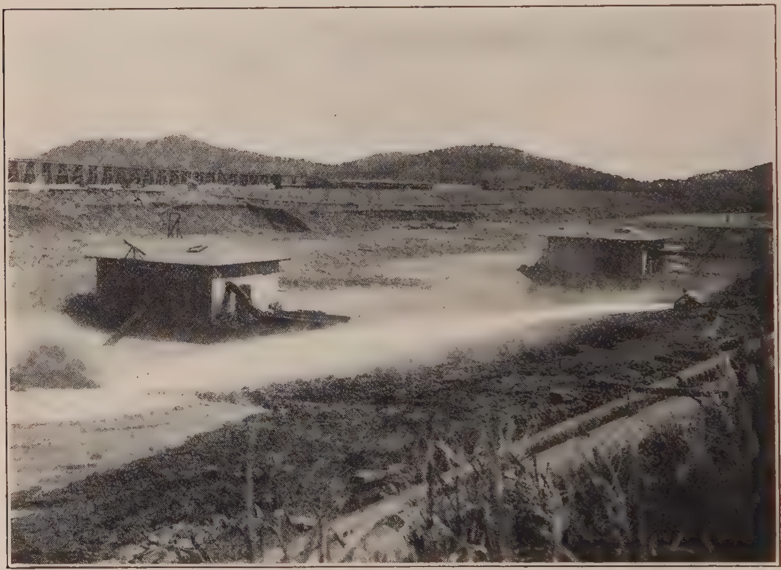


Fig. 10. Hydraulic Excavation, Miraflores Dredging Barges.

were secured together and sunk progressively. The bottom section had a metal cutting edge, and the earth inside of the shells was excavated by hand, during the process of sinking, loaded into buckets and hoisted by windlasses. The caissons were 15 feet (4.57 m.) apart and a battery of windlasses, operated by a single engine, was arranged for sinking an equal number of caissons at the same time. Well drills were also utilized as windlasses to increase the number of caissons that were to be sunk simultaneously. The caissons were eventually filled with concrete and supported a system of heavy rein-

forced-concrete girders, which in turn supported the walls of the superstructure.

Concrete Lamp Posts.

A large number of lamp posts were required for lighting the locks. These and the caisson shells, referred to above, were manufactured and stored in a yard established at Miraflores between the lock and cement shed; half-yard (0.38 cu. m.) mixers were installed in the yard in such a way that the concrete could be poured directly into the moulds.

Paper No. 13

DREDGING IN THE PANAMA CANAL.

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The subject above includes mention, at least, of the French companies' work of this kind, and it would be impossible, within the limits of this article, to do much more than treat it briefly.

Dredge excavation as shown on the ground at the time of the American occupation consisted of a channel dug from Limon Bay, through the present Cristobal harbor to a point near Bohio, 14.5 miles from the dry dock at Cristobal, this channel being 150 to 225 feet wide, the wider parts being apparently passing points; the water varied in depth from one to eighteen feet, owing to siltage.

Various traces of dredging and stranded dredges were found at Bohio, Mile 15; Chagrecito, Mile 21; Mamei, Mile 25; Gorgona, Mile 29, on the Atlantic side of the Divide. On the Pacific side a channel was dug from deep water in Panama Bay to La Boca wharf, passing to the east of the Islands of Perico, Naos, etc., which channel was maintained by the Panama Railroad when this work was assumed by the Canal Commission. Above La Boca wharf a channel was excavated a distance of 12,000 feet, carrying about eight feet at low water.

Excavation useful to the American canal was estimated by a committee and is treated at some length in the Canal Record, Vol. 3, page 124, issue of December 15, 1909. The Committee states it is impossible to determine between wet and dry.

The dredges which were used by the French in performing this work were of two types: The ladder, or endless-chain bucket dredge, and the suction dredge.

The ladder dredges can be subdivided into five kinds, as follows:

1. Four small 60-hp. ladder or elevator dredges operated by sprocket-chain drive, with buckets of nine cubic feet capacity and molded hull. Further details are not available. One dredge was sunk at Mindi, the others scrapped. The foregoing were the first dredges on the Isthmus.

2. Marine type, self-propelling dredges which came to the Isthmus under their own steam. They were three in number, one on the Atlantic side and two on the Pacific, and were built by Lobnitz & Company, of Renfrew, Scotland. They had molded hulls of 170 ft. by 26 ft.; single-screw; direct inverted compound engines of 300 hp.; dredging gear driven through frictions by sprocket chains; Scotch marine boilers; 17 cubic feet capacity buckets, with 32 to 36 buckets in the endless chain; and center well. They were unable to cut their own flotation on account of the projecting bow, and apparently were bought for outside work in deepening channels; they were fitted for use in a considerable seaway. These dredges were named "A-1", "A-2" and "A-3"; "A-1" and "A-2" were rebuilt by the Americans and called "Mole" and "Gopher". The dredging depth of the first two was 12 meters; the other, 10 meters. (See Plate I.)

3. The Belgian non-propelling dredge, with rectangular box hull, 112′ 2″ by 29′ 6″ by 11′ 6″; Scotch marine boilers; and tandem steeple engines of 180 hp., directly connected to dredging gear. They were erected on the Isthmus from Belgian makers and apparently were the principal reliance of the French companies. The buckets were of 17 cubic feet capacity, with 32 to 36 in the endless chain; the dredge was able to cut its own flotation. Twenty-two of these dredges were purchased by the French and are accounted for as follows:

17 dredges erected and operated for two years by the French companies,
1 burned at Colon in 1885,
1 at San Pablo, not completed,
1 at Gorgona,
1 at La Boca, hull only,
1 lost in transportation.

These dredges were interchangeable in all parts—machinery, plating, frames, etc. (See Plate II.)

4. Four dredges, details incomplete; size about 120 ft. by 30 ft.; ladder built in two pieces; belt transmission; two chutes, 180′ long, for dumping; spoil dumped on banks of Canal back of wooden dams, or bulkheads; dredges were not successful except in soft material; said to be of American make.

When the dredges reached Colon, the French company paid one-half purchase price, the balance to be paid on completion of project. When the project was abandoned, the receivers protested payment of balance due, and Slavin Company (contractors) took possession of the dredges and sold same to the Nicaraguan Canal. Three of these dredges sank en route to Greytown, and the other was not operated after arrival.

5. Two dredges known as Suez. This type was a box-hull ladder dredge which discharged its buckets into a well, where the contents were diluted with water and taken up by a centrifugal pump and discharged on shore through an overhead pipe line carried on a barge alongside. Only two of this type are known, and they apparently had not handled any great amount of material; and they were said not to have been successful, as rocks continually plugged the chute. (See Plate III.)

Ladder Dredges.

All dredges in this class were built either of steel or iron.

In operating all classes of ladder dredges, except those discharging through chutes or pipes on shore, mud scows were necessary, and the outfit provided with the first class of ladder dredges was what was called ''hand clapets''. These were small iron hopper barges of about 130 cubic meters capacity, dumping through bottom doors, and towed by steam launches to dumping ground; also some 100- to 150-ton barges, from which material was removed by elevator hoist and deposited on canal banks through chutes 120 feet long.

To handle material from classes 1, 2, and 3 of ladder clapets, 12 steam self-propelling mud scows were purchased, known as ''Clapets''. These dredges, 136′ 6″ by 26′ 3″ by 14′ 6″, had twin compound inverted engines of about 350 hp., Scotch marine boiler, and a hopper capacity of 250 cubic yards. Eight were built by Lobnitz & Company, Renfrew, Scotland,

(see Plate IV), and four by Palmer, of Jarrow, England, (the Jarrow clapets are slightly different in dimensions from the Lobnitz). There were also four single-screw clapets, 133′ 6″ by 25′ 1½″ by 11′ 0″, with 2-cylinder compound engines, 21 in. by 42 in. over 24 in., of 365 i.h.p.; Scotch marine boilers, and a hopper capacity of 250 yards; these dredges were built by Lobnitz & Company. All of the above boats were built of steel or iron.

Below is given a partial list of the other marine equipment used by the French companies in connection with dredging and transportation. Some of this equipment was in comparatively good condition, and the rest was practically worthless.

2 150-hp. steam launches.
1 Craneboat, 40 tons capacity (La Valley, still in commission),
1 Craneboat, 5 tons capacity,
1 Pontoon clam-shell dredge (small),
1 Steam drill-barge; built somewhat on plan of American drill barge "Teredo",
12 Lighters (100 and 150 tons capacity) for transporting coal, water, etc.,
4 Wooden lighters, equipped with sails, for coal service (sunk at Mindi, Gatun, Gatuncilla, and Trinidad),
2 Steam launches, 35 hp.,
4 Lobnitz steam launches, 150 hp.,
4 Lobnitz steam launches, 100 hp.,
5 Lobnitz steam launches, 75 hp.,
4 Lobnitz steam launches, 50 hp.,
2 Lobnitz steam launches, 35 hp.,
2 Small tugs named "Falcon" and "Game Cock",
2 Clam-shell dredges, small (not erected),
2 Water boats, steam; Sanidad type,
9 Steam launches, 150 to 35 hp.

Suction Dredges.

Four suction dredges were purchased by the French companies (see Plate V); two worked at San Pablo and two at Gorgona. In 1889, a freshet in the Chagres River grounded one of the Gorgona dredges and sank the other three. In the following dry season all were recovered. These dredges had

iron box hulls, 70′ x 19′ x 9′, and were equipped with a 16-inch centrifugal pump, belt-driven, and Scotch marine boilers. Subsequent to the purchase of the above suction dredges, 22 small barges with dimensions approximately similar to the foregoing, were equipped with "Invincible" English-make centrifugal pumps. Only 14 of the 22 were put in service; for these dredges were not found suitable, on account of ineffective pumps.

Later, a scheme for using hydraulic monitors (sluicing) was tried out, with water pressure furnished by three high-power pumps mounted on launches. Five of these outfits were built, but they were not found satisfactory.

THE AMERICAN DREDGING, ATLANTIC DIVISION.

The Atlantic Division comprises the reach from deep sea in Limon Bay to and including the Gatun Dam.

The dredging in this Division was begun by the use of Belgian Dredge No. 1 of the ladder type (see Plate II), which operated during 1905 and 1906 in keeping open the passages into the Colon and Cristobal wharves. The material handled was soft mud, with some coral sand and rock.

Mr. F. B. Maltby, Division Engineer, assumed charge of all dredging in this and the Pacific Division early in the year 1905, and Ladder Dredge No. 1 was handled under his direction. A small 12-in. dredge, constructed of an old French hull and a modern American pump, was built in 1906 and started on the excavation of the French Canal from Dry Dock to Mindi, that part of the French Canal having silted up to such an extent that only a row boat could pass along it. This excavation was necessary to allow rock from Porto Bello crushers and sand from Nombre to reach the Gatun site; cement was also sent in barges from the ship's side through this channel, and much of the dredged material from the canal, at the intersection of the French Canal, was passed out this route and dumped in deep water.

The plans for the seagoing suction dredges "Ancon" (afterwards named "Caribbean") and "Culebra" (see Plate VI), sister ships, based on the seagoing dredges "Atlantic" and "Manhattan", used in New York Harbor, also the plans for the pipe-line double-suction 20-in. dredges, No. 82, No. 83,

''Sandpiper'' and No. 85 (see Plate VII), were made in 1905, 1906 and 1907, under Mr. Maltby's direction.

The contract for the seagoing suction dredges ''Ancon'' and ''Culebra'' was given to the Maryland Steel Co., Sparrows Point, Maryland, at $362,425.00 for each dredge. The ''Ancon'', the first dredge received, arrived at Cristobal in August, 1907, and as soon as it could be placed in proper condition for work, which was about two weeks later, began excavating the new channel.

During the year 1905, bids were received from several builders of dredges for furnishing two five-yard dipper dredges delivered complete, ready for service on the Isthmus, one on the Atlantic and one on the Pacific side.

The dredge ''Chagres'' (see Plate VIII) was built on the Isthmus, having been received knocked down, and went into commission at Cristobal in March, 1907.

Belgian ladder dredges Nos. 1, 5 and 6 were rebuilt from time to time in the dry dock at Cristobal, and were placed in commission as soon as ready. Spoil from these and the 5-yard dipper dredges was handled by French clapets and the 400-cu. yd. mud scows that were purchased in the States in 1907 and 1908.

Deck lighters, launches, oil barges, etc., were purchased or built at Cristobal.

The Panama Canal from deep sea to Gatun is in two tangents, with a slight curve to the right at Mindi, near the crossing of the French Canal; and the material to be dredged, from Mile 0 at the 42-foot contour of Limon Bay, to Mile 3, was composed almost entirely of silt and was removed by the seagoing suction dredge ''Caribbean''.

The material from Mile 3 to Mile 3½ was composed of silt, coral rock, and soft blue rock, and was dredged by ladder and dipper dredges; Mile 3½ to Mile 4½, the shore line of Limon Bay, the material was silt with occasional beds of soft rock, removed by ladder and dipper dredges; Mile 4½ to intersection of French Canal, the material was soft blue rock and hard clay. This section was bored by well drills, holes being bored about 15 feet each way and carried five feet below grade required, or 46 feet below mean tide; as many as 150 holes were ex-

ploded at a time. These holes were not sprung, but were filled with 60% dynamite from bottom to top and exploded with the ordinary detonator, with current furnished from the lighting plant of one of the dredges. This method was devised by Mr. Wm. Gerig, Division Engineer, who succeeded Mr. Maltby as Division Engineer, February 1st, 1907.

Intersection French Canal to Mile 6: Mindi Divide, soft blue rock, blasted and excavated in the dry by steam shovels; boring done by tripod and well drills, the pit being kept free from water by pumps during the progress of the work.

Mile 6 to Gatun Locks: Mud, clay and occasional soft rock areas; almost all excavated by pipe-line suction dredges.

All dredging done in this division has been divided among the various kinds of material to be handled in the most advantageous way; viz., the various suction dredges handled the softest materials, consisting of silt, sand, etc., while the French ladders and the 5-yard dippers handled the various harder strata, consisting of coral rock and the characteristic argillaceous sandstone that is the prevailing rock on the Atlantic side.

Table I gives a list of the dredging equipment used in this Division.

Dredging Fill in Gatun Dam.

Dredging work on Gatun Dam was begun in December, 1908, by cleaning all objectionable material from the area to be dredged. Two borrow pits were made, one south and one north of the dam.

Rock retaining walls were made, by dumping rock from railroad tracks on both the north and south toes of the dam, and the hydraulic material was deposited between these walls. An efficient system of drainage was provided by installing two sets of drain pipes, with three 20-in. pipes, with light flange and bolt connections in each set. These pipes were carried on a slight up-grade through the rock toes near the original ground level until near the axis of the dam, along which a bonding ditch about 20 ft. wide and varying in depth had been cut; a ninety-degree elbow was here connected, with the projecting end of the pipe vertical, and short sections of pipe added from time to time as the fill progressed, about one foot depth of

TABLE I.

Plant—Atlantic Dredging.

Name	Type	Dimensions	How acquired	Complement Officers	Complement Men	Remarks Cost or appraised value
Nos. 1, 5, and 6	Ladder dredges	112′ x 29′ 6″ x 11′ 6″	From French; rebuilt Cristobal Drydock 1907-9	5	40	*$ 35,000 each
No. 3	Clam shell	112′ x 29′ 6″ x 11′ 6″	From French; rebuilt Cristobal Dry-dock 1908	3	21	
No. 4	18-in. Pipe-line	112′ x 29′ 6″ x 11′ 6″	From French; rebuilt Cristobal Dry-dock 1908-9	11	58	$153,261
Nombre	12-in. Pipe-line	80′ 8″ x 16′ 5″ x 7′ 7″	Hull from French; Morriss 18-in. pump, water tube boilers, rebuilt Cristobal Drydock 1910	11	58	
Sandpiper No. 82, No. 83	20-in. Pipe-line	124′ 3″ x 36′ 6″ x 9′	Purchased from Maryland Steel Co., Sparrows Point, Md., 1908	11	58	$98,550
No. 86	20-in. Pipe-line	150′ x 40′ x 10′ 6″	Purchased from Ellicott Machine Corp., Baltimore, Md., 1910	11	58	$160,000
Mindi	5-yd. dipper	110′ x 38′ x 11′	Purchased from Featherstone Fndy. & Mchy Co., Chicago, Ill., 1906	4	27	$100,000
Chagres	5-yd. dipper	110′ x 38′ x 11′	Purchased from Atlantic Gulf & Pacific Co., Cristobal, C. Z., 1907	4	27	$98,550
Caribbean	20-in. sea-going suction	288′ x 47′ 6″ x 27′	Purchased from Maryland Steel Co., Sparrows Point, Md., 1907	9	57	$362,425
Clapets—						
No. 12, No. 14	Self-propelling dump barges	138′ 6″ x 25′ 6″ x 15′ 10″	From French; rebuilt Cristobal Dry-dock 1905-10	4	20	$20,000 each
No. 3, No. 4	Self-propelling dump barges	140′ 3″ x 26′ 6″ x 14′ 6″	From French; rebuilt Cristobal Dry-dock 1905-10	4	20	$20,000 each
No. 2	Self-propelling dump barges	136′ 6″ x 26′ 3″ x 14′ 6″	From French; rebuilt Cristobal Dry-dock 1905-10	4	20	$20,000
Tugs—						
Balboa	Supply tender	60′ x 12′ x 8′	From French; rebuilt Laboca Ship-ways 1906-7	2	10	$10,000
DeLesseps	" "	67′ 6″ x 15′ x 9′	From French; rebuilt Cristobal Dry-dock 1909-11	2	10	
Gatun	Sea-going tug	101′ x 22′ x 12′ 6″	Built in Philadelphia, Pa., 1902, purchased in New York, 1906	4	26	$42,000
Bohio	" " "	104′ x 21′ x 11′ 6″	Built in Camden, N. J., 1905, purchased in Norfolk, Va., 1908	4	26	$57,000
Porto Bello	" " "	126′ x 23′ 5″ x 14′ 5″	Built in Baltimore, Md., 1906, purchased 1907	4	26	$55,000
Empire	" " "	120′ x 24′ x 14′ 6″	Built Port Richmond, N Y, 1909, purchased 1909	4	26	$75,500
Nine dump scows used in the dredging service, 126′ x 31′ x 10′ 6″, built by the Newport News Ship-building & Drydock Company, Newport News, Va., and towed to the Isthmus in 1908						$26,083 each
La Valley	Crane boat	160′ x 40′ x 15′	From French Canal Company; operated by Panama R. R. Co. until American canal operations commenced			$23,500
Terrier	Drill boat	72′ 6″ x 18′ 6″ x 7′ 6″	From French Co.; French barge hull rebuilt at Cristobal Drydock in 1910 and battery of churn drills mounted for subaqueous rock excavation			$3,000

Above equipment served by miscellaneous steam and gasoline launches, floating piledrivers, lighters, etc.

* No. 6 sunk June 19, 1911.

water being placed on the surface of the fill to avoid scour and waste of material.

This method forced considerable drainage through the rock toes, and deposited large quantities of dredged material in the rock, thereby reducing settlement of the dry fill and making it more impervious to water.

The dredged material varied from a black alluvial soil on top, at elevation + 5 feet, to a hard, tough, red clay below at elevation — 36 feet, which varied in density in different parts of the borrow pits.

Up to August, 1909, all hydraulic material had been taken from north of the dam; after this date, from both north and south.

By December, 1909, the surface of the fill had reached an elevation which, owing to the length of pipe-line, made it impracticable to continue without relay pumps. The cost of dredging at this time had risen to $0.167 per yard.

Twenty-inch electric-driven centrifugal pumps, directly connected to 550-hp. motors, supplied with current at 2200 volts, were installed on the toes of the dam, with centers at elevation + 35 ft.

The first of these relays was started on January 23, 1910; the second, one week later, on the north side, eastern section; and the third, on the south side, March 2nd of the same year.

It was found desirable to discharge the dredged material into both sides of the fill simultaneously, thereby depositing the coarser and heavier material along the rock toes and forcing the light and less desirable material to the center, allowing it to be wasted through the drains situated on the axis of the dam. Also, by this method, a great amount of the lighter and more undesirable material was passed through the toes and out of the drain pipes. Borrow pit measurements show that 16,528,897 cubic yards were deposited; only 10,728,965 cubic yards of which remain in the completed dam.

As the dam height increased, it was found that elevation + 72 feet was about the economical limit for a dredge with the assistance of one relay pump; above this height, two relays were used.

Dredges and relays were moved from time to time to get

different classes of material, it being the policy not to allow a heavy deposit of one class of material, but to obtain a uniform ultimate mixture of clay and sand.

A dredge storehouse for supplies and spares was located at Gatun; the repair shops were located at Cristobal, seven miles distant by water.

In spite of the distance to the repair shop and the losses—which varied from 65.8% in 1912 and 34% in 1911, to 30% in 1909 and 1910, caused almost entirely by material in suspension being carried off through drains—material was handled at a cost of \$0.2768 per cubic yard for net embankment in place, and \$0.1938 per cu. yd. on the basis of borrow-pit measurement.

The plants handling this work were 20-in. split, or double suction, pump dredges, Nos. 82, 83, 84 and 85, equipped with tandem compound Ideal engines, with 12-in. and 22-in. by 16-in. cylinders, 170 to 200 r.p.m., 150 lbs. steam pressure, and developing about 540 indicated hp. for each pair, driving 84-in. shrouded impellers; and 20-in. single-suction Dredge No. 86, with 96-in. diameter impeller driven by a triple-expansion marine-type engine, cylinders 14 in.—22½ in.—40 in. by 20 in., 190 to 200 r.p.m., steam pressure 200 lbs., developing over 800 hp. All pumps, dredges and relays, were fitted with removable liners and impeller shroud plates, throat rings, etc. All dredges were built by the Maryland Steel Company, and the Ellicott Machine Company, both of Baltimore, Maryland.

Experience showed that in placing hydraulic fill at high elevations with dredges of the double-suction type used, elevation + 35 and a pipe-line of 3000 feet length was about the economical limit; that a 20-in. electrically-driven relay pump, with 550-hp. motor, located at this elevation (+ 35) would deliver through 3000 feet of pipe to + 70 feet; and that a second relay at about elevation + 70 would in turn deliver through 3000 feet of pipe to an elevation of + 105 (9000 feet of pipe in all), in quantities to place heavy sand and clay, during the last months of the fill and extreme elevation, at a cost of \$0.1863 per cubic yard, which was slightly below the average for the entire fill.

This work was under the charge, as Resident Engineer,

of Major Geo. M. Hoffman, Corps of Engineers, U. S. Army, and Mr. Charles A. Black as Superintendent.

The Inner Harbor at Cristobal.

The development of the inner harbor at Cristobal has been a gradual growth, as the scheme is located in and by the French Canal, about ½ mile distant from the American Canal channel. The opening of the French Canal from Limon Bay to the Dry Dock was necessary, as on this part of the channel the wharves for construction material were built, although all commercial freight in the early days of the Canal was handled at the Colon wharves. Harbor enlargements were made and commodious, modern, ferro-concrete wharves were built outside of Cristobal Point, on land reclaimed from the sea, and a channel excavated from the French Canal to the wharves.

The French Canal north of the Dry Dock was also enlarged, and a modern coaling station is being built on the west side, with railway communication to Cristobal by a swing bridge, one-quarter mile south of Dry Dock.

Material excavated in the harbor and approach channel consisted of silt, coral, coral sand and the characteristic blue argillaceous sandstone of the Atlantic section.

Twenty-inch pipe-line suction dredges, French ladder dredges, seagoing hopper dredges, and 5-yard dippers, have excavated this harbor.

Material: 4,915,727 silt; 924,960 coral; 28,097 rock.

Dredging for the Breakwater, Colon.

No dredging was done for the west breakwater in Limon Bay, although large quantities of material excavated from the Canal and the harbor were dumped along the sea or outer face, this being an economical haul for the dredged material and also adding to the breakwater volume.

The ground elevation of the line of the east breakwater is about — 42 feet, and a double trestle, carrying two lines of railroad track with frequent cross-overs, has been built along the axis of the breakwater. Rock is dumped on both sides of this trestle up to about elevation — 20 feet, when the rock dumping is discontinued and coral sand and rock are pumped in from a 20-in. suction dredge at Coco Solo Point, about a mile distant from the breakwater. More rock is then dumped, and

sand fill made up to — 12 feet, when the sand fill is discontinued and the crown is made of Sosa rock. Coral rock from the harbor excavation and hopper contents from suction dredge "Caribbean" are also dumped on the toes and in the line of the breakwater.

It is intended to deposit this special sand and coral rock fill over the entire line of the east breakwater, the material to pass from the dredge through one and two electric relays on the trestle. Until the first relay can be built, however, the material from the shore dredge is directly relayed through a second 20-in. dredge, about 1500 feet distant from the first. Rough seas make this arrangement necessary.

It is thought that this method of building a breakwater is original.

Nombre de Dios Sand Dredging.

The construction of the locks at Gatun required approximately 1,000,000 cubic yards of sand, and, after searching both the Atlantic and Pacific Coasts for material, it was finally determined by the then Division Engineer to procure this material at the old Spanish port of Nombre de Dios, where a sand bank had formed from the detritus of two small rivers. This required a 25-mile haul, through rough seas; and as some silt had settled on top of the sand, it proved quite expensive to handle.

Sand at Nombre was handled by various methods, among them being: (1) dipper dredge to take off the top silt, followed by a 16-in. pipe-line dredge, discharging directly into barges; (2) locomotive crane, with clam shell, on shore handling into cars, dumped from trestle into barges; a double-ended 2-cu. yd. bucket, clam-shell dredge, and, lastly, an 18-in. pipe-line dredge, No. 4.

Operations were begun at Nombre de Dios in March, 1909, and closed in November, 1911, during which time there was secured from this pit, and put in storage, 785,893 cubic yards of sand, at an average cost of $1.9176 per cubic yard.

43,851 cubic yards of sand were dredged by 20-in. pipeline dredge immediately below the dam at Gatun at a cost of $0.5188 per cubic yard. The remainder of the sand required was dredged at Chame Point, on the Pacific Coast, unloaded at

Balboa Sand Handling Plant, and transported to Gatun on railroad cars.

PACIFIC DIVISION.

This division extended from Pedro Miguel to the 45-foot mean-tide contour in the Bay of Panama, and the dredging work consisted in the excavation of the 500-foot bottom width channel from Miraflores locks to the above mentioned contour; also the completion of the fresh-water channel of similar width in Miraflores Lake, which had been partially excavated by steam shovels.

The plant available on the Pacific side for this work included four French ladder dredges—"Mole", "Gopher", "Marmot", and "Badger"—of which the first two were of the marine type (see Plate I), and the second two of the "box" or Belgian type (see Plate II), each with an endless chain of 17-cubic-foot buckets, running 14 to 18 to the minute. Considering their power, these dredges were very efficient in the softer material of this channel, the record for French ladder dredges being held by the "Marmot", with 219,795 cubic yards in one calendar month.

The remaining dredging plant comprised one 5-yard dipper dredge, "Cardenas" (see Plate VIII), similar to the dredge "Chagres" of the Atlantic Division; one twin-screw seagoing suction dredge, the "Culebra" (see Plate VI), with two 20-in. suction pumps discharging into self-contained hoppers holding 2200 yards, similar to dredge "Caribbean" in Atlantic Division; and one modern twin-screw ladder dredge, the "Corozal" (see Plate IX), with mud buckets of 54 cubic feet capacity, and rock buckets of 34 cubic feet, and able to excavate 50 feet below the surface of the water.

From section 2285,—the junction of the American and French Canals, a point about 2000 feet south of the old French wharf at Balboa—to deep sea, the material to be excavated consisted altogether of silt and clay. The shoaler parts of this stretch, and the heavy clays of the bottom, were excavated by the French ladder dredges, and the spoil dumped from the mud scows to the west of the Canal.

From section 2285 northward, the material consisted of a top layer of silt, then stiff clay and then rock of different de-

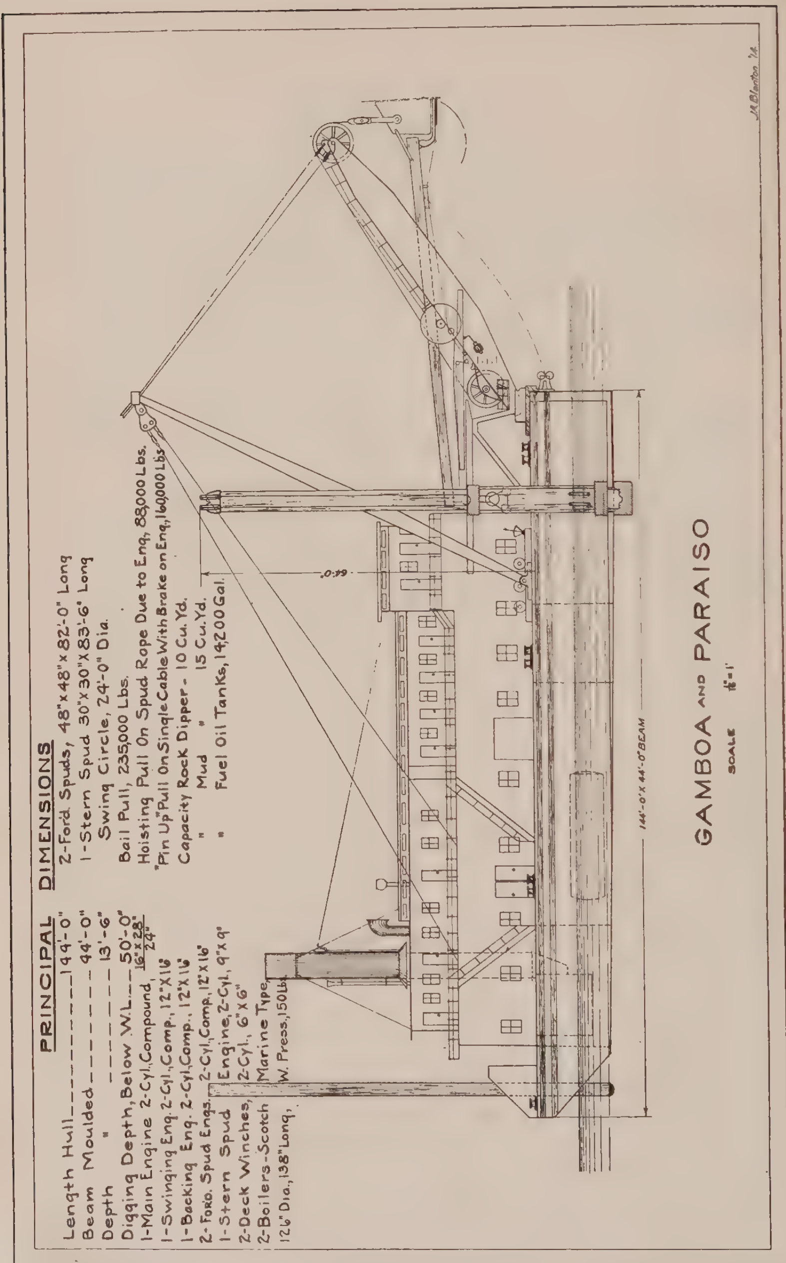

PRINCIPAL DIMENSIONS
Length Hull ---------- 144'-0"
Beam Moulded -------- 44'-0"
Depth " ---------- 13'-6"
Digging Depth, Below W.L. ---- 50'-0"
1-Main Engine 2-Cyl., Compound, 16"x28"/24"
1-Swinging Eng. 2-Cyl., Comp., 12"X16"
1-Backing Eng. 2-Cyl., Comp., 12"X16"
2-Ford. Spud Engs. 2-Cyl, Comp, 12"X16"
1-Stern Spud Engine, 2-Cyl, 9"x9"
2-Deck Winches, 2-Cyl., 6"X6"
2-Boilers-Scotch Marine Type, 126" Dia., 138" Long, W. Press., 150 Lb.
2-Ford. Spuds, 48"x48"x82'-0" Long
1-Stern Spud 30"X30"X83'-6" Long
Swing Circle, 24'-0" Dia.
Bail Pull, 235,000 Lbs.
Hoisting Pull On Spud Rope Due to Eng, 88,000 Lbs.
"Pin Up" Pull On Single Cable With Brake on Eng, 160,000 Lbs.
Capacity Rock Dipper - 10 Cu. Yd.
" Mud " 15 Cu. Yd.
" Fuel Oil Tanks, 14,200 Gal.
64'-0"
144'-0" X 44'-0" BEAM
GAMBOA AND PARAISO
SCALE 1/8"=1'

Plate X.

grees of hardness, especially hard rock shoals occurring at sections 2074 (Miraflores lock) to 2135, 2140 to 2150, 2160, 2188 to 2200, 2215 to 2225, 2260, and 2280. Over the intervening sections soft rock of varying degrees of density occurred from 10 to 25 feet thick.

The 3-drill boat, ''Teredo'' (see Plate XII), was used on most of the hard rock work. The rock was drilled in 5-foot sections, and the holes were loaded from the bottom of the drilled hole, 5 feet below the grade required, to the surface of the hard rock with special 2 in. by 8 in., 60% dynamite cartridges; about 2.5 lbs. of explosive being used to the cubic yard of rock. The holes were exploded weekly.

Where the hard rock required to be removed to a depth of only a few feet, the Lobnitz rock breaker, ''Vulcan'' (see Plate XIII), operating first a 19- and afterwards a 22½-ton ram, was used, with centers four feet apart. The hard rock was broken into small fragments and afterwards dredged by a French ladder dredge. Repeated dredging was required as the layers were broken up, from 1.5 feet to 3 feet being removed at each dredging.

In order to avoid the delay and expense of breaking or blasting, it was thought that a high-powered modern dredge would cut the softer rocks in the section from Balboa Wharf to Miraflores lock. On this assumption the ''Corozal'' was purchased, and proved amply able to handle this work with an output varying from 3000 to 10,000 yards of rock per 24-hour day; the harder parts of the soft rocks were handled by cutting 6-inch layers, the softer as much as 4 feet at one passing of the dredge. This dredge also was very efficient in the rock of the harder shoals, after blasting by the ''Teredo'', but not so efficient in the Culebra Cut work, where very large pieces of rock were encountered in places where there was not sufficient depth of water for the dredge to get directly over the rock.

Excavation was begun in the sea entrance of the American channel, June 1907, by the French ladder dredge ''Mole'', at Section 2371, in about 18 feet of water, low tide; the material was loaded in French steam dump scows or clapets, and dumped on a short haul ½ mile to the west of the line of Canal. The 5-yard dipper dredge ''Cardenas'' was put into commission

at about the same time, at the intersection of American and French canals, and the material was also handled in clapets. The two 20-in. pump suction dredge ''Culebra'' went into commission in January, 1908, excavating the channel seaward from the initial cut of the ''Mole''. The new channel was opened to commercial shipping from the 45-foot contour, Panama Bay, to La Boca wharf, February 1, 1909, other dredges being added from time to time as they were rebuilt or purchased and put in commission.

The material north of Station 2155 to Miraflores locks, Station 2075, being mostly hard rock, was planned to be taken out by dry excavation, and a coffer-dam was built across the canal at the former station and partially excavated by means of hydraulic nozzles and sump pumps. Star drills and dry blasting were then used to break up the rock, and the rock almost entirely taken out, from Miraflores Lock to Station 2114.

It was thought that the dredges could take out the blasted rock cheaper than the steam shovels, and being pressed for time, a second coffer-dam was built at Station 2114 and all material south of this site was excavated by the dredges, including the coffer-dam at Station 2155; when this was completed the second coffer-dam was removed by the dredges, thus flooding the channel to the locks.

The ladder dredge ''Corozal'' and two of the French ladder dredges were removed to Culebra Cut, on account of more urgent work there, in November, 1913; and this channel, although equal to all the demands of commerce, is not completed at the present date, March 1, 1915, there remaining 685,300 yards of earth and 524,200 yards rock to be excavated.

Hydraulic Excavation.

It was originally planned to excavate the material, other than the rock in the lock site for the Miraflores lock and the Canal channel itself, for a distance of 1½ miles south of Miraflores lock, by means of a hydraulic excavation plant, as a large part of this material was required in the Miraflores Dam, to confine the water of Miraflores Lake to the 55-foot level. The remaining material was to be used in reclaiming the swamps in the neighborhood, the underlying rock, to required grade, to

be excavated by steam shovels. This plan was thought necessary because of the difficulty of placing hydraulic dredges in this area.

Two principal operations were involved, viz., disintegrating the material and washing it to sumps by means of water jets under high pressure, and lifting and conveying the material through flumes by means of dredging pumps.

The plant consisted of the following parts:

1st. A central pumping station.
2nd. Pipe lines and hydraulic monitors.
3rd. Dredging pumps.

The pumping station was centrally located, with reference to the area to be excavated, on the bank of the Rio Grande west of the Canal, on a rock foundation. The pump room was 50 by 100 feet, boiler room 40 by 100 feet. Four Worthington horizontal, direct-acting, triple-expansion pumping engines with 24-inch stroke, $24\frac{1}{2}$-in. water cylinders, 19-, 30- and 50-inch steam cylinders were installed. Each pump was provided with a surface condenser and a direct-acting, single-cylinder 12- by 20- by 24-inch vacuum pump. All pumps discharged into a common delivery pipe and were equipped with the necessary check and gate valves.

The boiler equipment consisted of four Babcock & Wilcox water-tube boilers, each boiler with 4500 square feet of heating surface and designed for working pressure of 150 lbs. without superheat, and arranged for using either oil or coal as fuel. The steel smokestack was 9.5 feet by 150 feet; fuel oil tanks of 4000 barrels were located nearby.

Pipe Lines and Monitors. The supply main from pumping station was 3600 feet long, and consisted of 2000 feet of 40-in., 800 feet of 32-in. and 800 feet of 24-in. spiral riveted pipe, in 30 feet lengths. There were five air valves in the main line and 12 tees for connecting branch lines to monitors; the branch lines were 16-in. spiral pipe; the hydraulic giants or nozzles, fitted with special deflecting nozzles, were manufactured by Joshua Hendy Iron Works.

Dredging Pumps. The pumps were three 18-in. single-suction, centrifugal dredging pumps direct connected to a 655-

horsepower inductive motor, and were designed to lift 10,000 gallons per minute of salt water with 10% solid matter against a head of 60 feet.

The motors were Westinghouse standard, designed for three-phase alternating current at 2080 volts and 25 cycles. Each pump, together with its motor, switchboard and priming pump, was mounted on a reinforced concrete barge.

Method of Operation. Two dams were built, one across the bed of the Rio Grande, west of the Canal, and the other across the Canal at Station 2155, diverting the river by these means. The water in the enclosed area was lowered by pumping until just enough remained to float the barges, and the giants operated in the vicinity of the barges, so as to lower them to bed rock, partially flooding the cut when necessary to move the barges. The dredge pumps lifted the diluted material into the dam and on to the dump.

Some modifications of the above operations were made from time to time to meet conditions; chiefly in abandonment of the concrete barges and the placing of dredge pumps directly on the rock.

The amount excavated by this method during the life of the plant on this site was 1,549,904 cubic yards, at an average cost of $0.6959 per cubic yard, the entire plant charge, $432,-841.92, being absorbed.

The Harbor at Balboa.

The plan of the harbor involved the dredging of 97.1 acres of the tidal marsh at the mouth of the Rio Grande, and a part of the river itself. This harbor has been dredged almost altogether by pipe-line 20-in. suction dredges, and is now—Feb. 1, 1915—about 75.3% completed. The dredging has been carried on in connection with the shore work of building the necessary wharves and piers, a wharf or section of a wharf being built in the dry, by sinking the necessary concrete or steel caissons and completing the superstructure, after which the dredge excavated along the front of it to the depth required.

The material consisted mostly of silt and clay with occasional small rock shoals, with part of the west toe of the old Sosa Corozal Dam; the silt was removed by pipe-line and sea-

going suction dredge, and the rock shoals and old dam trestle and fill, by French ladder dredges.

All pipe-line dredging material has been deposited in the swamps north and east of the New Administration Building at Balboa Heights, through one, and at times two, electrically-driven relays, depending on the length of the pipe-line. These relays were made necessary by the tidal oscillations in Balboa harbor, at times as much as 20 ft., and the extreme length of line, about 14,000 feet from the dredge.

The amount credited to pipe-line dredges over the work is 4,941,268 cubic yards, at a cost of $0.1524 per yard.

The amount removed by ladder dredges, of clay, rock and silt, was 486,996 yards, at a cost of $0.2645 per yard.

Sand—Pacific Division.

Large quantities of sand were required for building purposes, especially for the concrete in the Pedro Miguel and Miraflores locks. An extensive system of borings was made at Chame Beach, about 25 miles west of Panama, in the protected harbor of Chame Bay, for the purpose of determining the quantity and quality of the sand that could be procured from this site. The amount of sand available was about 5,000,000 yards —a good, clean, white, silica sand, except that it was rather fine for concrete purposes; but, as it proved of much better grade than any other sand on either side of the Isthmus, it became the standard sand for use on the Isthmus; and eventually practically all sand used on the Zone came from this beach.

This beach was protected from the swells of the Pacific by a promontory south of the bay, although not protected from the off-shore trade winds during the dry season.

It was first proposed to handle this sand by a pipe-line dredge, but owing to the rough weather prevailing during four months of the year, the "Gopher", one of the French marine type, 17-cu. ft. bucket, ladder dredges, was used. This dredge proved well adapted for this work, and was continued in service during the whole construction period, being retired only from time to time for needed repairs, when its work was temporarily assumed by a dredge of similar design.

One tug and six 500-yd. barges were used in the service

TABLE II.

Plant—Pacific Dredging.

Name	Type	Dimensions	How acquired	Complement Officers	Complement Men	Remarks Cost or appraised value
Dredges—						
Cardenas	5-yd. dipper	110′ x 38′ x 11′	Purchased from Atlantic Gulf & Pacific Co., Balboa, C.Z., 1906-7	4	27	$94,500
Corozal	Modern ladder	260′ x 45′ x 19′ 6″	Purchased from Wm. Simons Company, Ltd., Renfrew, Scotland, 1912	8	63	$399,540
Culebra	20-in. sea-going suction	288′ x 47′ 6″ x 25′	Purchased from Maryland Steel Co., Sparrows Point, Md., 1907	9	57	$330,000
Marmot and Badger	Ladder	112′ 2″ x 29′ 6″ x 12′ 6″	From French, rebuilt Balboa 1908-9	5	40	$65,000 each
Gopher and Mole	Ladder	170′ x 26′ x 12′	From French; Gopher rebuilt Balboa 1907-8. Mole operated by Panama R. R. until American canal operations began	5	40	$54,000 each
Clapets—						
Nos. 1, 5, 6, 7, 8, 9, 10 and 11	Self-propelling dump barges	133′ 6″ x 25′ 1″ x 11′	From French; rebuilt Balboa 1905-10	4	20	$22,500 each
Tugs—						
Bolivar	Sea-going tug	127′ 1″ x 23′ 2″ x 9′ 5′	Built at Philadelphia, Pa., 1885	4	26	$28,000
LaBoca	" " "	120′ x 24′ x 13′	Built in Camden, N. J., 1907; purchased New York, 1907	4	26	$57,600
Cocoli	" " "	96′ x 23′ x 12′ 4″	Built in Philadelphia, Pa., 1904; purchased in New York 1907	4	26	$57,600
Chame	" " "	105′ x 20′ 3″ x 14′	Built in Hull, England, 1899; purchased Balboa, C.Z., 1907	4	26	$25,000
Miraflores	" " "	118′ 6″ x 23′ x 12′ 6″	Built at Wilmington, Del.; purchased 1910	4	26	$65,000
Reliance	" " "	134′ x 25′ x 13′ 6″	Built in Camden, N. J., 1906; purchased in Newport News, Va., 1908	4	26	$44,605
Barges—						
Nos. 20, 21 and 22	Dump scows	156′ x 35′ x 12′	Built by Newport News Shipbuilding & Drydock Co., Newport News, Va., 1908; towed to Isthmus; used in Atlantic dredging until 1912 when transferred to Pacific Dredge Fleet		2	$28,000 each
Three dump barges, 122′ x 31′ 6″ x 10′ 6″, purchased in the United States, delivered knocked-down at Laboca Shipways and re-assembled for dredging service, 1908						$24,300 each
Four dump barges, 154′ x 32′ x 10′ 7″, purchased in the United States, delivered knocked-down at Laboca Shipways and re-assembled for dredging service, 1910						
Rock Breaker "Vulcan"		100′ x 28′ x 8′	Purchased from Lobnitz & Co., Renfrew, Scotland, delivered knocked-down and re-assembled at Laboca Shipways 1908	2	10	$50,000
Drill Barge "Teredo"		112′ x 36′ x 8′	Purchased in United States, delivered knocked-down and re-assembled at Laboca Shipways 1909	2	44	$35,727

Above equipment served by miscellaneous steam and gasoline launches, floating piledriver, small boats, etc.

until June, 1912, when the barges were increased to nine, three barges having been towed from Colon by the Tug "Reliance", R. E. Thompson, Master, around South America, leaving Colon Feb. 11, 1912, and arriving at Balboa June 17, 1912.

Sand was towed to the sand-handling plant at Balboa, unloaded by electrically-driven clam-shell cranes into a hopper of 2000 cubic yards capacity, thence loaded into cars for transport to the various storage yards.

Sand dredging in Chame was begun in September, 1909, and up to October 31, 1914, the deliveries at Balboa aggregated 2,007,590 cubic yards, at a cost of $0.7789 per yard, delivered on the work or storage pile.

Wrecks.

Many small wrecks were found in the French channel and bed of the Rio Grande; those that appeared at low tide were cleaned out and patched sufficiently to float over to the west shore of the bay and allowed to fill with water. Two of these wrecks, however, were of French ladder dredges, in the prism proper, and these were cut up by dynamite and removed in pieces, slings being made fast at low tide to a scow over them and advantage being taken of the lift afforded by the high tide to break them loose from their bed, tow them to deep sea and drop them.

DREDGING IN THE CENTRAL DIVISION.

Almost all excavation in this Division was made by steam shovels, but quantities of material at low elevation and liable to overflow, in the neighborhood of Gamboa, were left for the dredges, as being more economical; also considerable material was left at Culebra and Cucaracha and in the various inclines, when the Gamboa Dyke was blown up on October 10, 1913.

The Division extends from Gatun to Pedro Miguel and comprises the channel through the Gatun Lake and Culebra Cut.

The work to date (November 1st, 1914) comprises the removal of the Gamboa Dyke, and the attack on and the removal of the various land slips locally known as slides, to which the territory on both sides of the Canal, from Empire, Mile 35.5, to 2000 feet south of Gold Hill, seems particularly prone. Each

slide has its own peculiarities, but they may be generally described as of three kinds:

1:—Where the material opens in a crack, the principal direction of which is parallel to the axis of the Canal, and from 100 to 1800 feet back of the prism line, the material gradually dropping in elevation and moving towards the Canal, this movement continuing until a slope is reached sufficient for repose. After the slide has become dead, the crack or fault sometimes presents a sheer cliff of some 80 or 90 feet, or if the material is sufficiently soft, a gradual incline.

2:—When the upper stratum is superimposed on an inclined, harder stratum with a sufficient slope towards the Canal to allow the upper material to slide in as through a chute, the surface of the harder stratum being lubricated by heavy rains.

3:—A combination of both the preceding descriptions.

The principal slides to be removed on the inception of dredging in this Division were Empire, Hagan, Culebra, New Culebra and Cucaracha; of these, Empire and Hagan contained only a small amount of material in the prism, which was readily removed by the small French dredges, and these slides are apparently dead at the present time.

The Gamboa Dam was a dirt fill on the bank of the Chagres River, and its office was to keep the Chagres River, which crossed the canal at this point, from overflowing into the Cut, the drainage from the Cut being handled by pumps over the dam; the dirt fill was on a rock foundation. It was also used for the passage of trains, it being for some time part of the main line of the Panama Railroad. The dam was mined by churn drills and shot October 10, 1913. The material was removed by French ladder dredges in the ordinary way, and without any particular trouble, except that the eastern half was not blasted to grade and required subaqueous drilling afterwards. On October 10, 1913, there remained north of Gamboa Dam 758,195 yards to be removed, and, up to date, there has been removed 507,195 yards, leaving 251,000 yards to complete the work.

The Cucaracha Slide.

This is the only slide of any magnitude that has developed south of the Continental Divide, and properly belongs to the

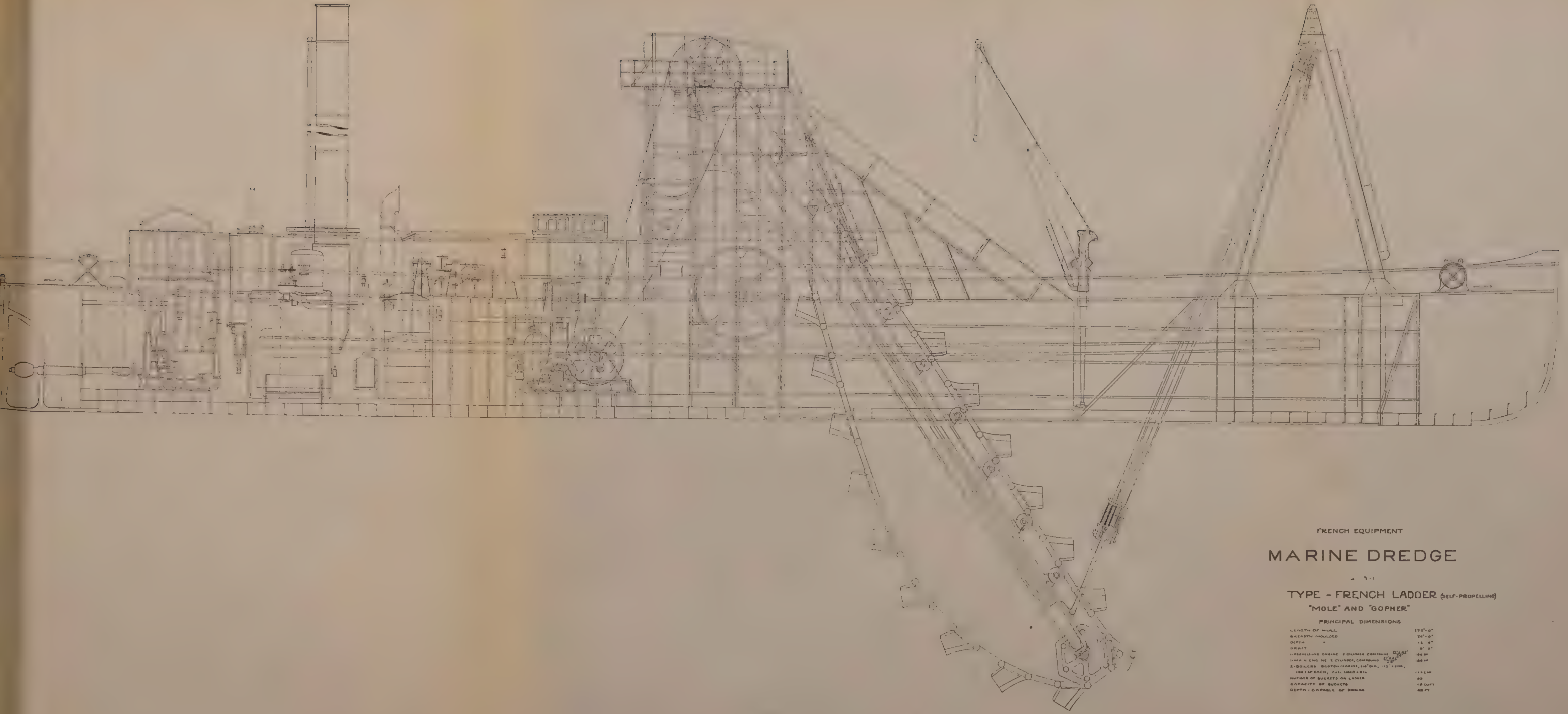

FRENCH EQUIPMENT
MARINE DREDGE
TYPE - FRENCH LADDER (SELF-PROPELLING)
"MOLE" AND "GOPHER"
PRINCIPAL DIMENSIONS
LENGTH OF HULL
BREADTH MOULDED
DEPTH
DRAFT
NUMBER OF BUCKETS ON LADDER
CAPACITY OF BUCKETS
DEPTH - CAPABLE OF DIGGING

Plate 1.

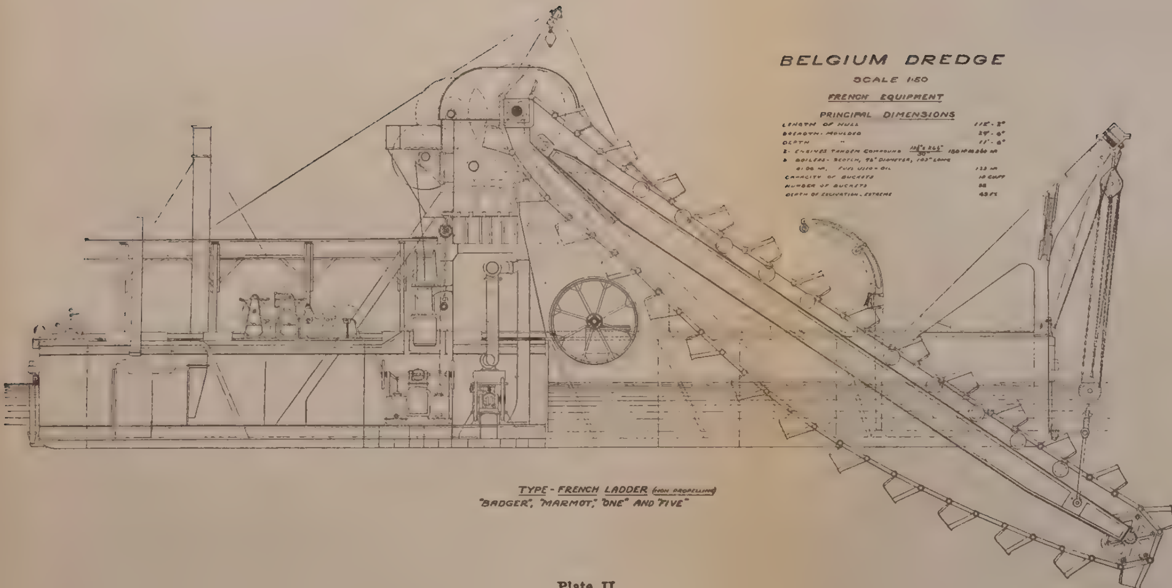

BELGIUM DREDGE
SCALE 1:50
FRENCH EQUIPMENT
PRINCIPAL DIMENSIONS
TYPE - FRENCH LADDER (NON PROPELLING)
"BADGER", "MARMOT," "ONE" AND "FIVE"

Plate II.

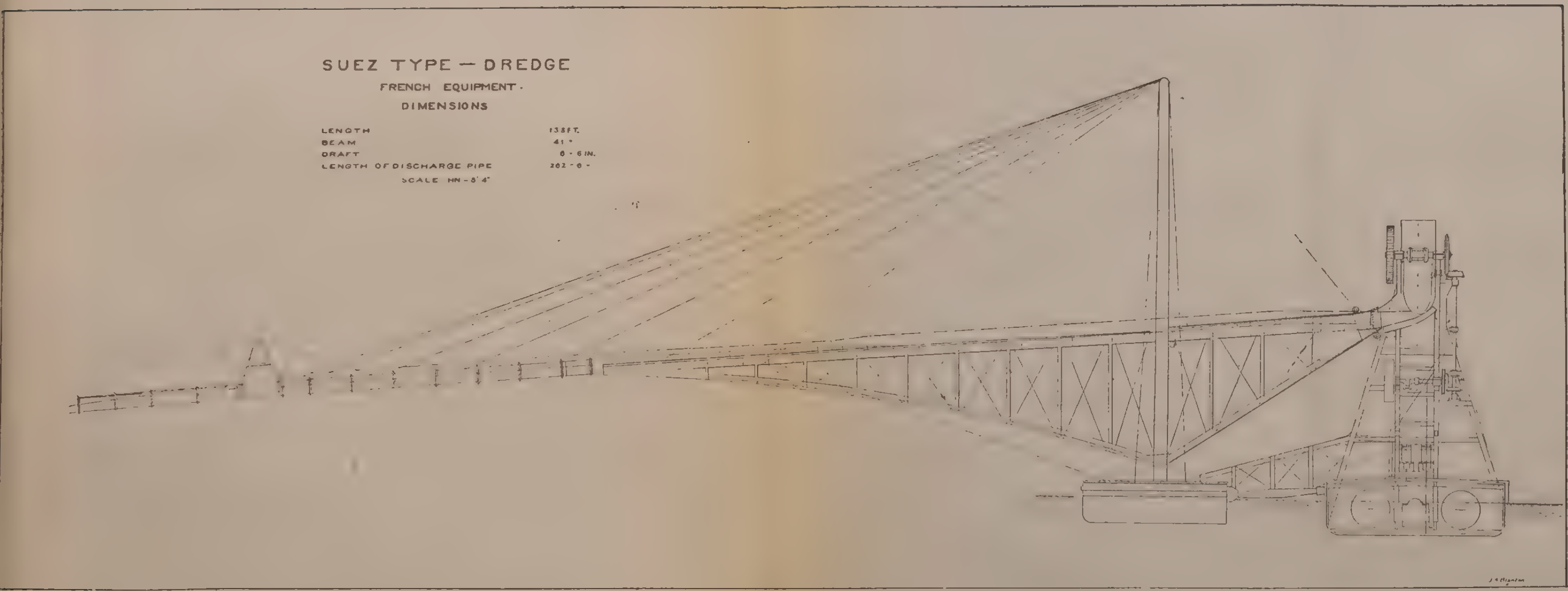
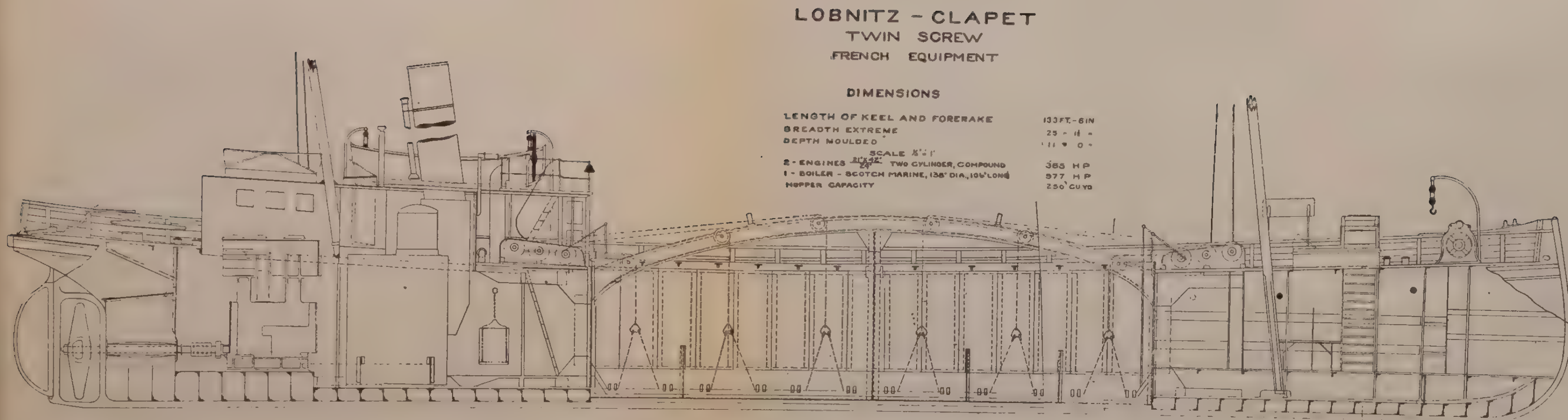
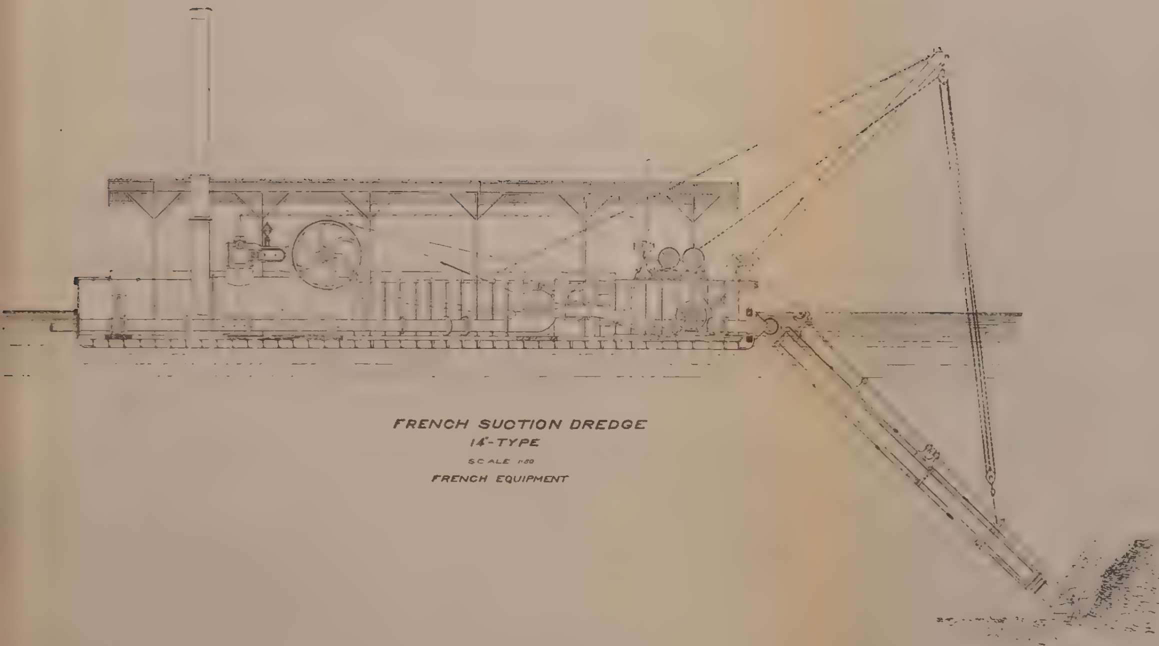

SUEZ TYPE — DREDGE
FRENCH EQUIPMENT.
DIMENSIONS
LENGTH 138 FT.
BEAM 41 "
DRAFT 8 - 6 IN.
LENGTH OF DISCHARGE PIPE 202 - 6 -
SCALE HN - 8' 4"

Plate III.



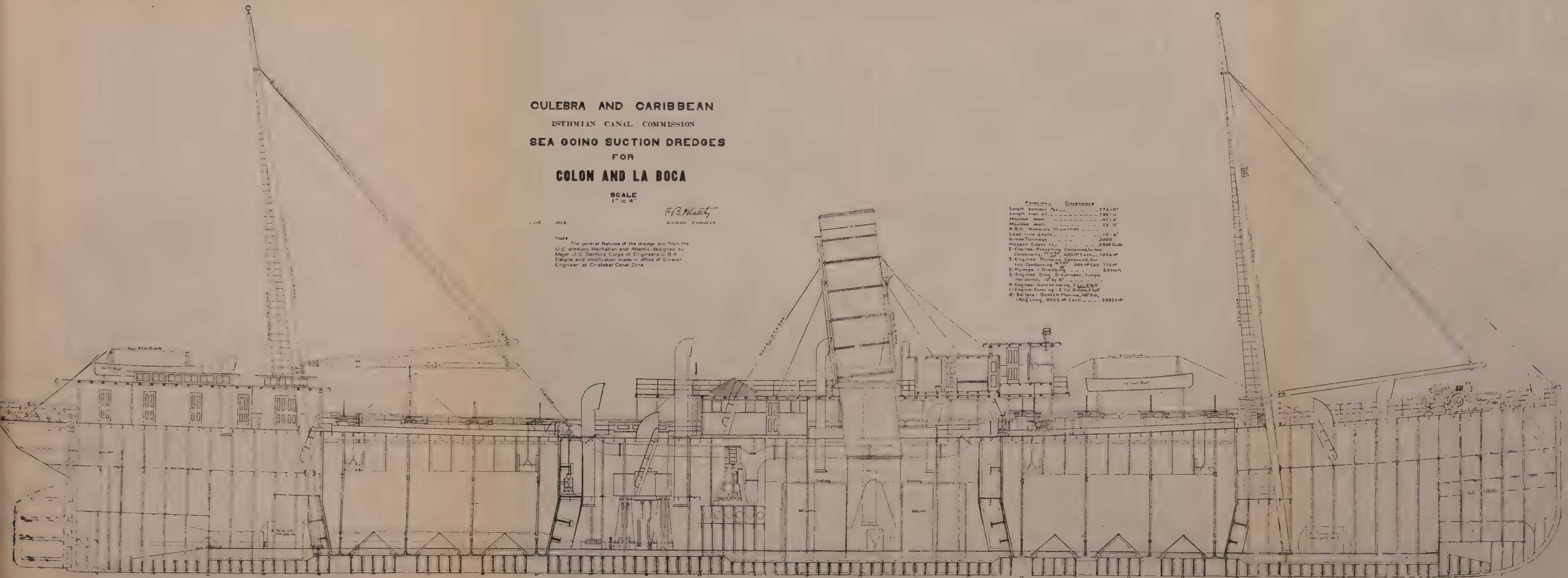
LOBNITZ - CLAPET
TWIN SCREW
FRENCH EQUIPMENT
DIMENSIONS
LENGTH OF KEEL AND FORERAKE 133 FT.-6 IN
BREADTH EXTREME 25 " 11 "
DEPTH MOULDED 11 " 0 "
SCALE ⅛" = 1'
2 - ENGINES 21"x42"/24" TWO CYLINDER, COMPOUND 365 H P
1 - BOILER - SCOTCH MARINE, 138" DIA., 106" LONG 977 H P
HOPPER CAPACITY 250 CU YD

Plate IV.



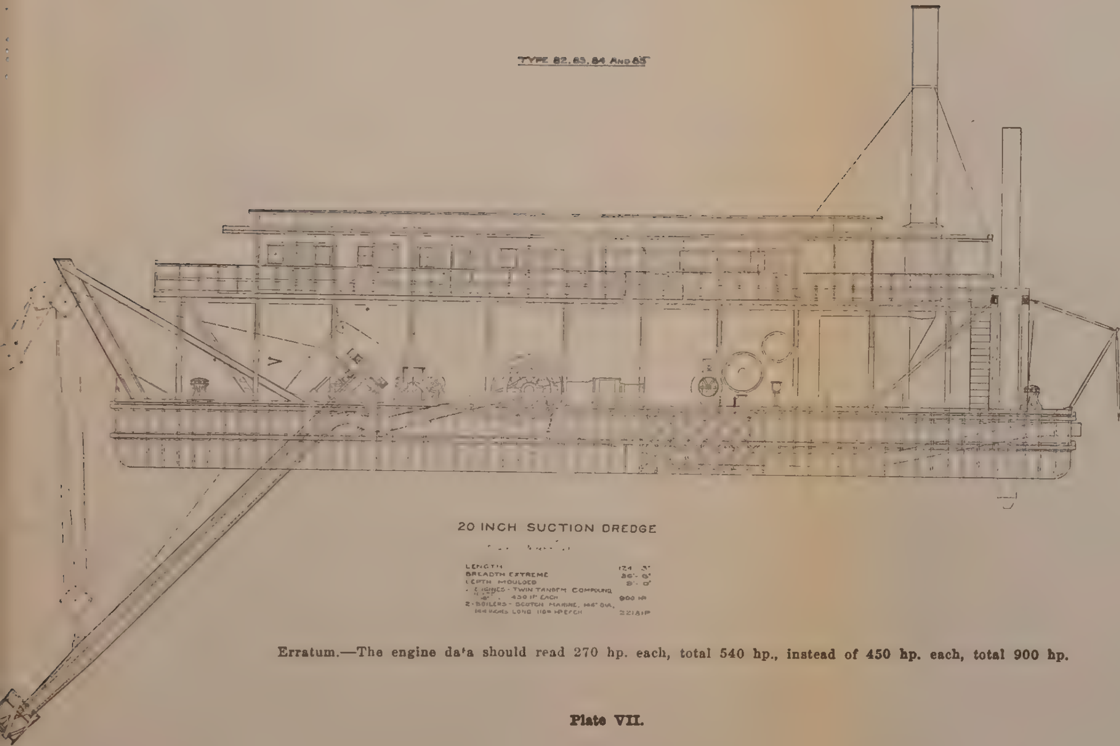
FRENCH SUCTION DREDGE
14"-TYPE
SCALE 1:50
FRENCH EQUIPMENT

Plate V.



LONGITUDINAL SECTION

Plate VI.



Erratum.—The engine da'a should read 270 hp. each, total 540 hp., instead of 450 hp. each, total 900 hp.

Plate VII.

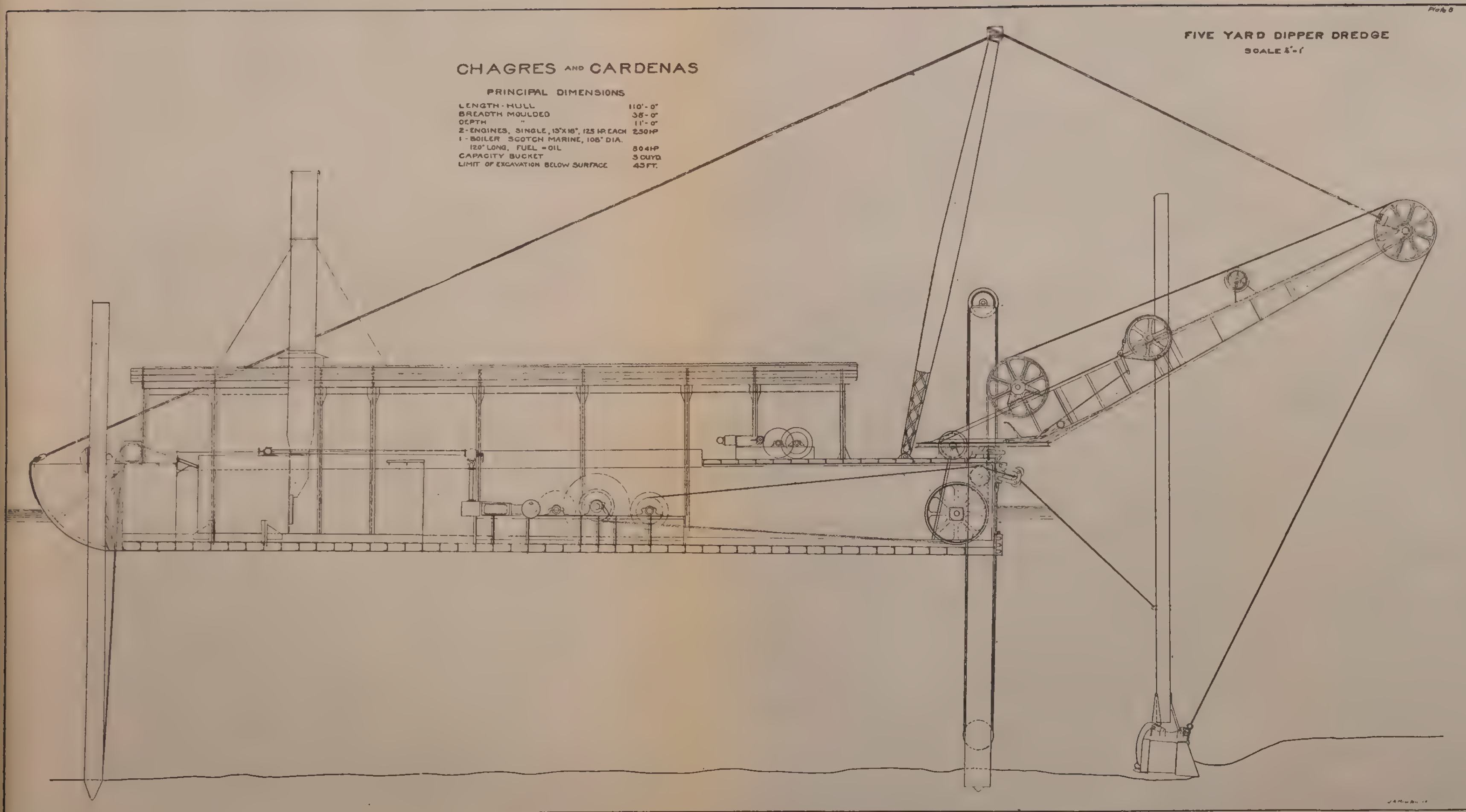


Plate 8
FIVE YARD DIPPER DREDGE
SCALE ⅛"-1'
CHAGRES AND CARDENAS
PRINCIPAL DIMENSIONS
LENGTH-HULL 110'-0"
BREADTH MOULDED 38-0"
DEPTH " 11'-0"
2-ENGINES, SINGLE, 13"X16", 125 H.P. EACH 250 HP
1-BOILER SCOTCH MARINE, 108" DIA.
120" LONG, FUEL = OIL 804 HP
CAPACITY BUCKET 5 CU.YD.
LIMIT OF EXCAVATION BELOW SURFACE 43 FT.

Plate VIII.

third class of slides previously mentioned. (See Plates XVIII, XIX, XX.) When the water was let into the Cut, this slide partially blocked the channel from Stations 1800 to 1809, and entirely so from 1809 to 1820, a distance of 2000 feet (see Plate XXI). The moving material broke loose a distance of 1700 feet east of the Canal prism at an elevation of from 500 to 600 feet above sea-level. The Cut was blocked so completely that several days elapsed before a narrow ditch could be cut and blasted to let the water south of the slide. This slide was on the east side of the Canal and immediately south of Gold Hill.

The Rio Grande Valley, on the west side and parallel to the Canal, at an elevation of 140 feet M.S.L. is about 3000 feet south and west of Cucaracha, and, as the southern part of the slide seemed composed principally of soft clay and small broken rock, it was planned to handle the material with two 20-in. open-pump suction dredges with 550-hp. electrical relays, mounted on the west berm above, and discharging into the valley. The northern part of the slide being almost entirely composed of broken rock, it was planned to handle the material with three 5-yd. dipper dredges, the spoil being loaded into barges and towed to Gatun Lake and there dumped into areas previously selected. It was also planned to use the large ladder dredge "Corozal".

Both suction dredges and two of the dippers were on the Atlantic side, and these suction dredges were needed on the south side of the slide. The "Corozal" was unable to make headway against the steep bank, so the old French ladder dredge "Marmot" was brought up from Balboa with two French dump scows, and a pioneer cut was made through, the spoil being temporarily dumped one half mile south of the slide. This pioneer cut was completed and a passage through the slide made on December 10, 1913, all dredges thus being enabled to take up their proposed stations.

On April 4, 1914, the new 15-yard dipper dredge "Gamboa", and on June 7, 1914, the similar dredge "Paraiso", were started at this work, six 1000-yard steel barges having been previously received.

There was excavated from this slide up to November 1, 1914, 3,552,259 yds. of rock and clay, at a total cost of $0.48

per yard; all spoil being pumped into the Rio Grande Valley or dumped from scows into the lake. At this date, the slide was apparently dormant, the channel being excavated to full width, with 34 feet of water at the shoalest point (see Plate

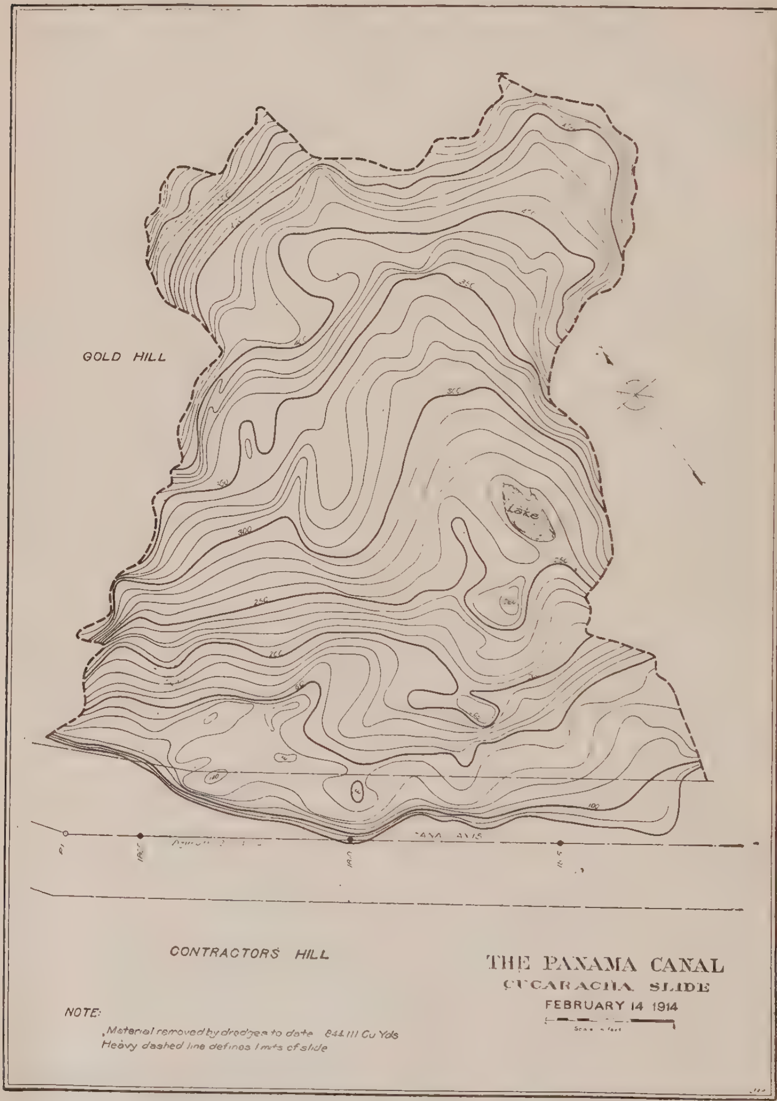


Plate XVIII.

XXII). The cost includes all charges for dredging, transportation and overhead expense.

No further movement of Cucaracha was noted until January 14, 1915, when the loose, superficial rock and clay, over

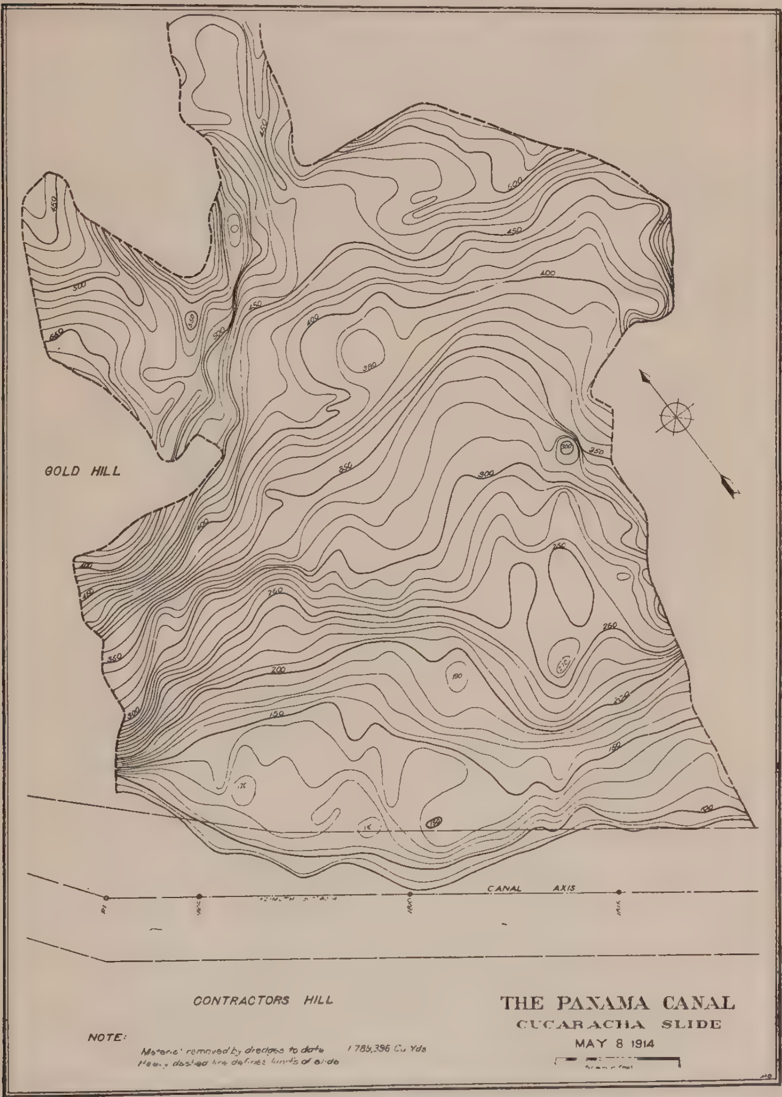


Plate XIX.

the underlying soft rock slopes, gathered enough force, under the changed conditions of the dry season, to put about 100,000 cubic yards into the Canal, with a consequent shoaling up of the east side of the channel from about elevation + 95 on the

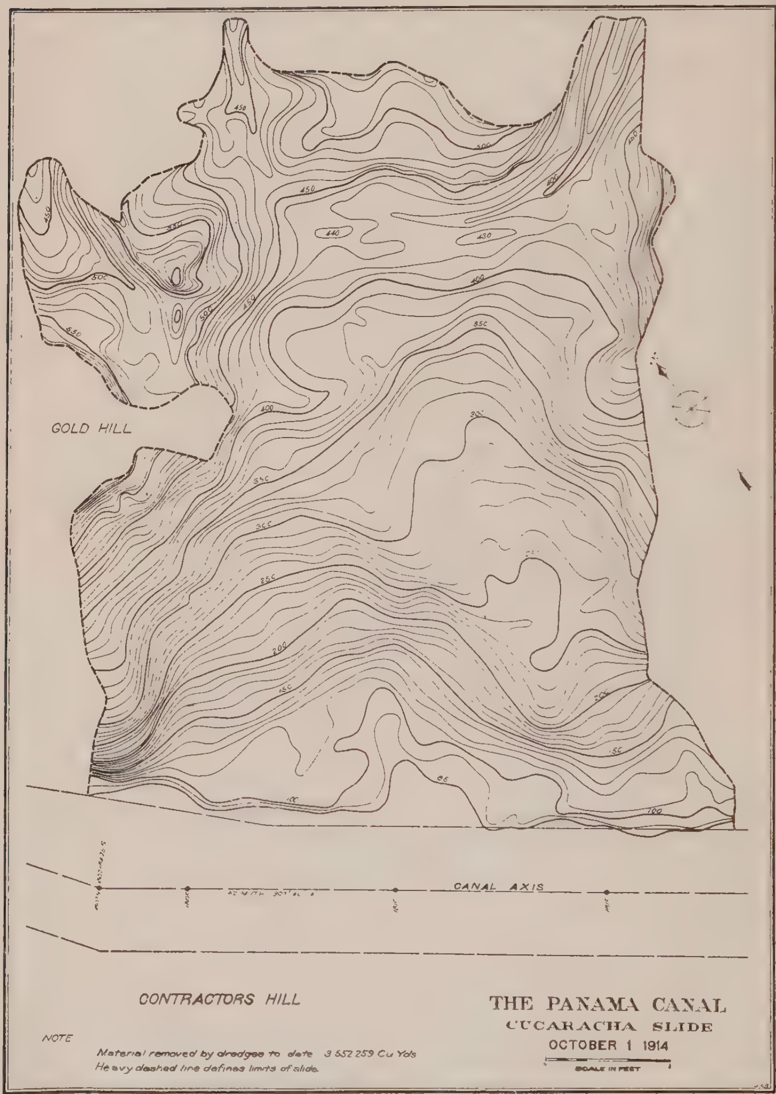


Plate XX.

east prism line to elevation + 75 feet on the center line, or only 12 feet of water. The ladder dredge "Corozal" was brought up from the Pacific side and the west side of the channel again cleaned up to 34 feet depth; this was done without delaying the passage of commercial shipping, and this part of the channel is in this condition at present, except that the hard rock has been broken to grade + 40 over nearly the whole of the prism at the slide, the dredges now being at more urgent work in Culebra Slide.

Five-foot contour maps are appended showing the condition at the beginning of the dredging, also near the present date (see Plates XXI and XXII).

Other Culebra Cut excavation, partly original up to September 30, 1914, totals 1,269,302 yards of rock and clay, at total cost per cu. yd. of $0.61785.

New Culebra Slide.

The banks of the Canal at Culebra rise to a height of 400 feet above sea-level (see Plate XIV), and are composed of mixed soft rock, clay, and occasional ledges of hard rock. These banks gave great trouble during the dry excavation period. Small slides from these areas have occurred during the past year, requiring the almost constant service of ladder dredge "Corozal". These small slides culminated on October 14, 1914, in one tremendous slide from the east bank, in which approximately 725,000 cubic yards of rock and clay moved into the prism in 12 hours, with an estimated amount of 5,000,000 cubic yards in the outside mass also moving, entirely closing the Canal to navigation (see Plate XXV), except for a tortuous channel with sufficient water for tugs. During this movement, the dredges were moved to the north side of the slide (about 6 P. M. on above date), and operations began before the slide had stopped moving; by 6 A. M. on the 15th, over 10,000 cubic yards had been removed, and up to November 1st, 346,368 cubic yards of rock and earth had been disposed of.

Another movement in the slide occurred on October 31, 1914, which showed itself mostly in an upheaval of the bottom of the navigable channel, and also some movement of the east bank.

Ship navigation was suspended from the 14th to the 20th

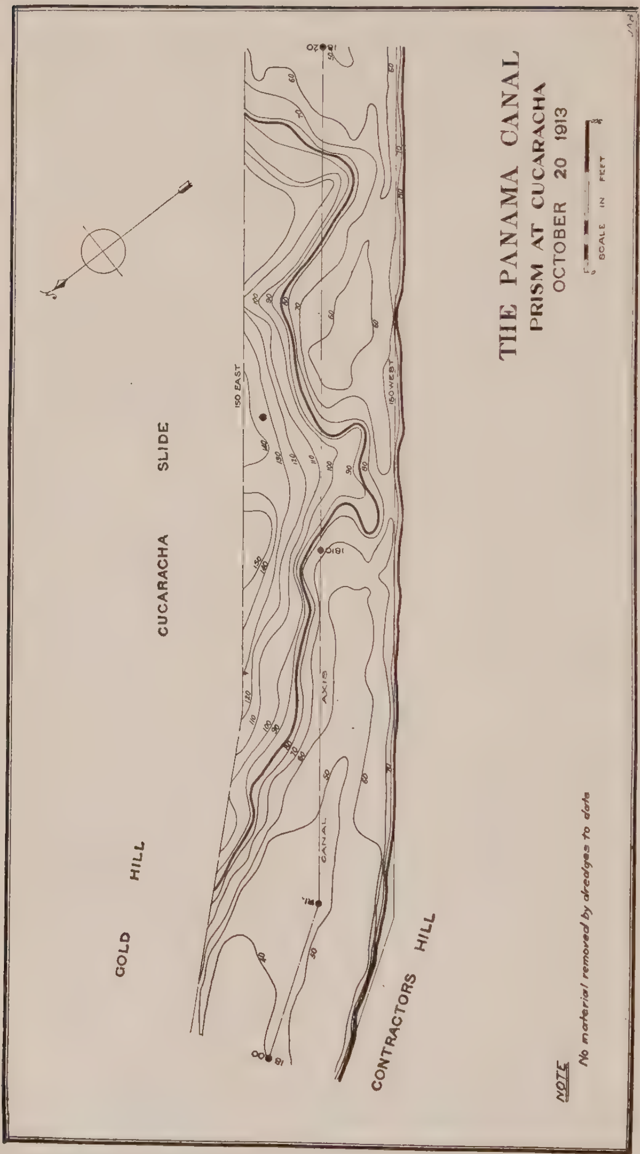

THE PANAMA CANAL
PRISM AT CUCARACHA
OCTOBER 20 1913
SCALE IN FEET
CUCARACHA SLIDE
GOLD HILL
CONTRACTORS HILL
150 EAST
150 WEST
CANAL AXIS
NOTE
No material removed by dredges to date

Plate XXI.

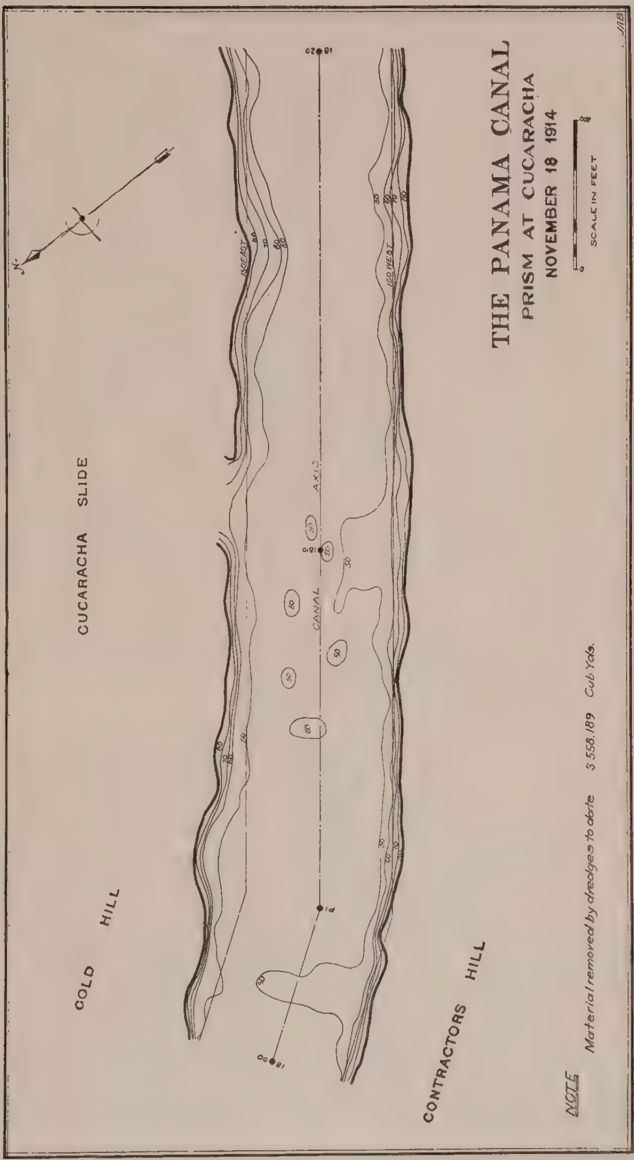

THE PANAMA CANAL
PRISM AT CUCARACHA
NOVEMBER 18 1914
SCALE IN FEET
CUCARACHA SLIDE
GOLD HILL
CONTRACTORS HILL
CANAL AXIS
150 EAST
150 WEST
NOTE
Material removed by dredges to date 3 558,189 Cub Yds.

Plate XXII.

of October, and from the 31st of October to November 4, 1914, and from March 4, 1915, to March 10, 1915.

Five dredges have been working on this slide since October 15, 1914; viz., the two 15-yard dipper dredges ''Gamboa'' and ''Paraiso'', the 5-yard dredges ''Mindi'' and ''Cardenas'', with the 5-yard ''Chagres'' as an alternate to the two former, and the 20-in. suction dredge No. 86. The amount of material taken out of this slide has been much reduced by the necessity of keeping open a channel for commercial shipping, and by the cramped quarters in the prism at the slide.

The rock and clay in this slide have been generally handled without blasting, and up to March 1, 1914, 2,477,679 cubic yards had been handled and transported to Gatun Lake and dumped, or pumped by suction dredge into Rio Grande Valley, an average of 550,593 cubic yards per month, at a cost including dredging, transportation, repair and overhead charges of $0.345 per cubic yard.

A general movement of this slide occurred again on March 4, 1915, caused by a movement of the accumulated loose material down the slopes.

Dredges are working continuously on this slide, except the stop for needed repairs, 7 days in the week, 24 hours in the day, including Sundays and holidays.

Gravel Supply.

The gravel bars of the Chagres have furnished material for ballast for the Panama Railroad and for various other purposes during the whole construction of the canal, a spur of the Panama Railroad being extended to the various bars, and material loaded by locomotive crane and clam shell into cars.

Flooding the canal stopped this source of supply, and to secure further supplies of this material, French ladder dredge No. 1 with barges, and French clapet, were placed in the service, and gravel procured from the bars of the river in the vicinity of the old Spanish town of Las Cruces, 2½ miles above the railway bridge. Two of the sand cranes were removed from Balboa and a wharf and bins were erected near the railway bridge over the river.

After this material had been delivered for some months, it was determined to screen the sand from the gravel, to take the

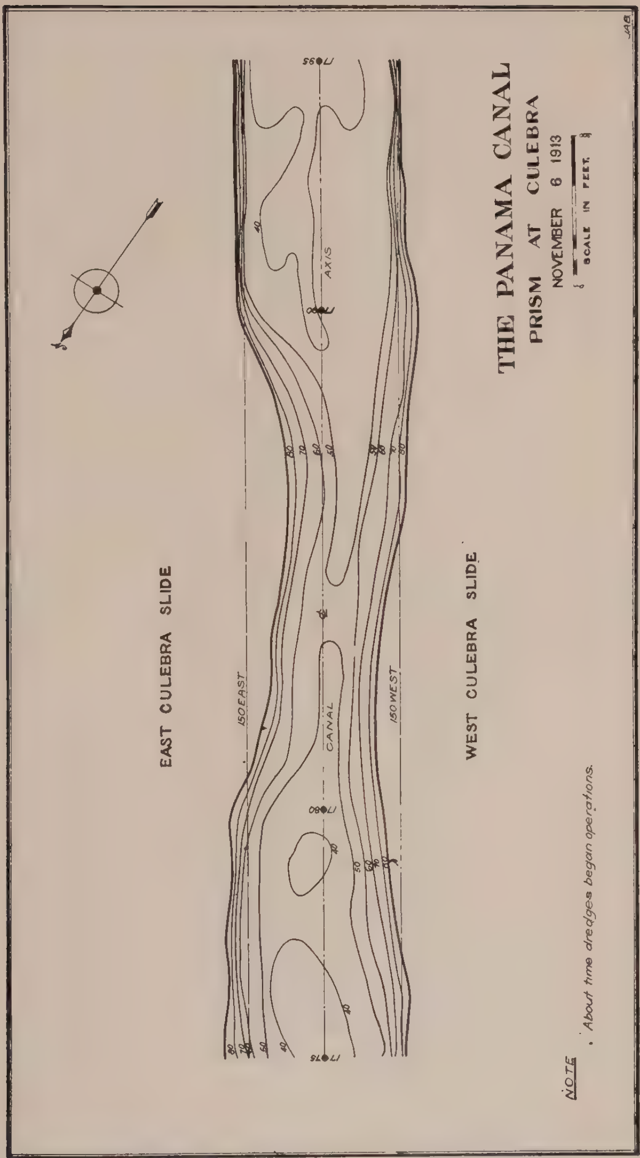

THE PANAMA CANAL
PRISM AT CULEBRA
NOVEMBER 6 1913
SCALE IN FEET.
EAST CULEBRA SLIDE
WEST CULEBRA SLIDE
150 EAST
150 WEST
CANAL
AXIS
NOTE
. About time dredges began operations.

Plate XXIII.

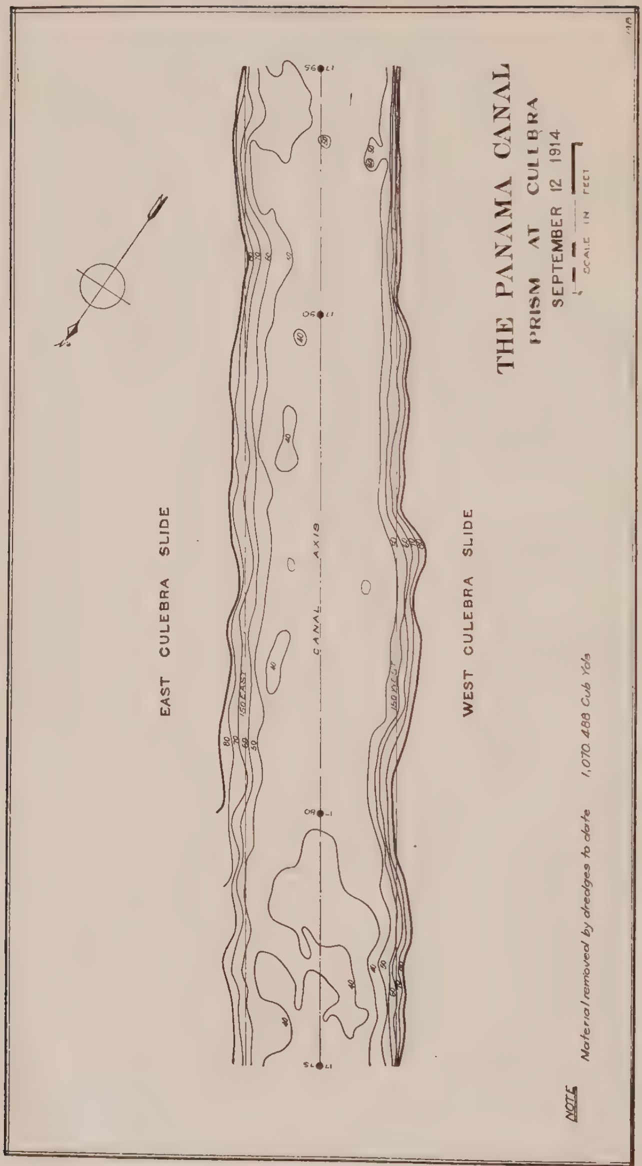

THE PANAMA CANAL
PRISM AT CULEBRA
SEPTEMBER 12 1914
SCALE IN FEET
EAST CULEBRA SLIDE
WEST CULEBRA SLIDE
CANAL AXIS
150 EAST
150 WEST
NOTE Material removed by dredges to date 1,070,488 Cub Yds

Plate XXIV.

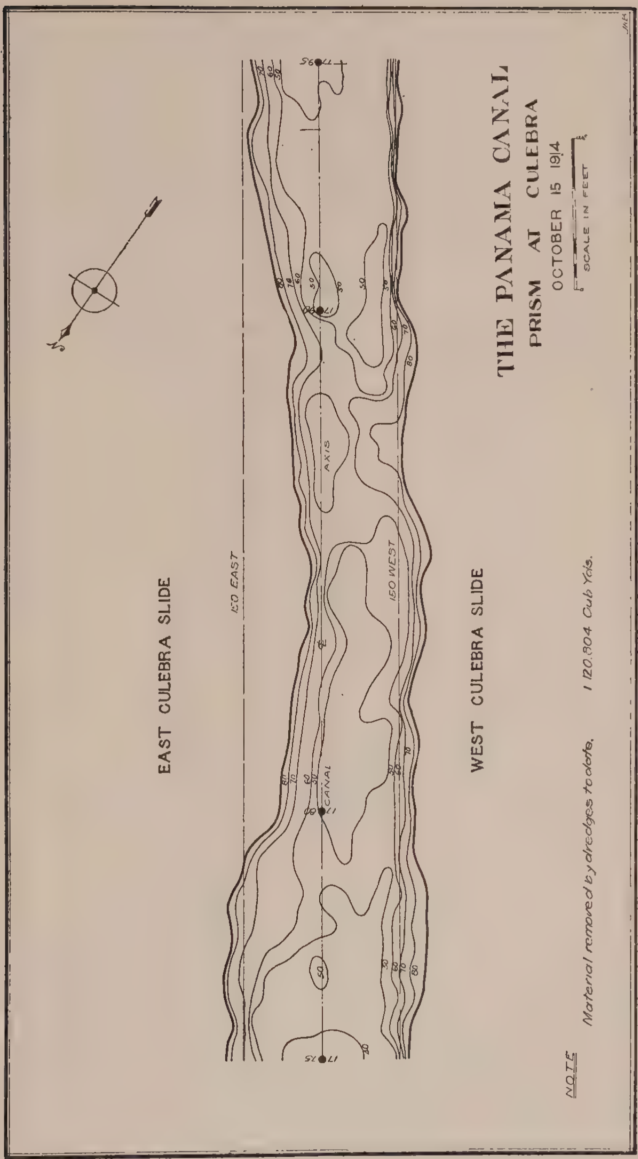

THE PANAMA CANAL
PRISM AT CULEBRA
OCTOBER 15 1914
SCALE IN FEET
EAST CULEBRA SLIDE
WEST CULEBRA SLIDE
150 EAST
150 WEST
AXIS
CANAL
NOTE
Material removed by dredges to date. 1 120,804 Cub Yds.

Plate XXV.

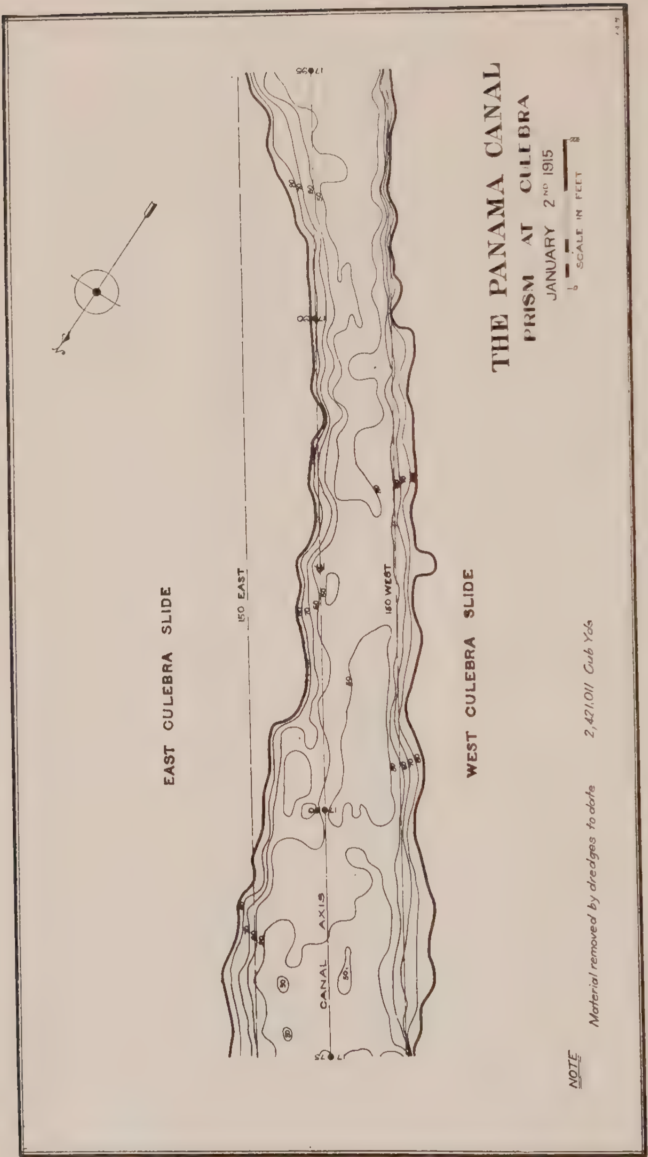

THE PANAMA CANAL
PRISM AT CULEBRA
JANUARY 2ND 1915
SCALE IN FEET
EAST CULEBRA SLIDE
WEST CULEBRA SLIDE
150 EAST
150 WEST
CANAL AXIS
NOTE
Material removed by dredges to date 2,421,011 Cub Yds

Plate XXVI.

place of Chame sand, the small amount of sand needed making the Chame plant too expensive.

A 20-in. suction dredge was then placed in service, retiring the French ladder, and the output directly pumped into two steam-driven 48-in. by 108-in. circular $1/4$-in. mesh screens and discharged through chutes into barges on each side of the screen barge. This screen was afterward changed to a steam-driven 9-ft. by 14-ft. double screen (inside plate 2-in., outside $3/8$-in.), which handled the entire output of the dredge, delivering No. 1 and No. 2 washed gravel sand, and by shutting a valve bank-run gravel.

395,800 cubic yards of material has been handled at a cost of $0.3416 per cubic yard delivered at the unloader plant.

THE PANAMA CANAL

TABLE OF DREDGE EXCAVATION

Total quantities and costs of all material removed from the Panama Canal and auxiliary works by dredging.

YEAR	CANAL PRISM					OTHER THAN CANAL PRISM					GRAND TOTAL OF DREDGE EXCAVATION				
	EARTH	ROCK	TOTAL	COST	UNIT COST	EARTH	ROCK	TOTAL	COST	UNIT COST	EARTH	ROCK	TOTAL	COST	UNIT COST
1905	111,376	0	111,376	23,04258	.2069						111,376	0	111,376	23,04258	.2069
1906	1832,959	83,500	1,916459	398,018,77	.2077						1,832,959	83,500	1,916469	398.01877	.2077
1907	2,306,611	43602	2,350,213	487832.08	.2076						2,306,611	43,602	2,350,213	487832.08	.2076
1908	10,348575	12,417	10,360,992	2,142,38740	.2068						10,348.575	12,417	10,360,992	2142,38740	2068
1909	14,211,569	417,621	14629,190	3,037,231.38	.2076	2,513,183	27889	2541,072	464,77417	.1829	16.724,752	445,510	17,170262	3,502,00566	.2040
1910	11,443462	369,421	11812883	2820561.98	.2388	4462263	179,152	4.641,415	1,641,05998	.3536	15.905,725	548,573	16,454,298	4,461 621,96	2712
1911	10,589837	788,150	11,377,987	2,68934438	.2364	7140,572	23739	7164311	2,675,47688	3595	17,730,409	811889	18,542,298	5,26482176	.2889
1912	7,774637	980,477	8,755,114	1946251.51	.2223	5.016,781	83648	5,100,429	2,283,07034	4476	17,791,418	1,064,125	13,855,543	4,229321,86	3052
1913	9,004,415	1,800,949	10,805,364	2,756,245 36	.2551	2,313,976	189284	2508260	945,315.04	.3776	11,318,391	1,990,233	13306624	370156040	2781
1914	7,165472	3863,169	11,028,641	3.381,92796	.3066	2990,506	283006	3,273,512	1,188,30640	.3630	10,155,978	4,146,175	14,302153	4,570,23436	3195
1915 *	1,123648	2507,904	3631,552	1,382,545.77	3807	3477,192	241,771	3,718,963	.816,44034	.2195	4.598,829	2,751,686	7,350,515	2,198 986 11	2992
TOTALS	75,912,561	10,867,210	86779,771	21.065,389.17	24275	27,914,473	1028,489	28,942,962	9.914,443.15	.3426	103·825 023	11,897,710	115.722,733	30.979,832.32	2677

Includes excavation for Locks, Dams, Terminals, Harbors, Sand and Gravel Service and all other auxiliary excavation.

* 6 months of fiscal year 1915 - July 1914 - to December 1914

THE PANAMA CANAL

PERFORMANCE OF FRENCH LADDER DREDGE No. 1

JULY 1, 1908 – JUNE 30, 1909.

Year	Month	Cubic Yards: Earth	Cubic Yards: Rock	Cubic Yards: Total	Cost	Unit Cost
1908	July	124820		124820	13.451.49	.1077
	Aug.	135.610		135.610	15.560.61	.1147
	Sept.	152.727		152.727	13.764.70	.0901
	Oct.	168796		168.796	13.258.25	.0786
	Nov	116.025		116.025	12.317.28	.1062
	Dec.	143.501		143.501	16.945.33	.1180
1909	Jan.	111 090		111.090	20.316.80	.1829
	Feb	90.634		90.634	24.729.61	.2728
	Mar.	118.051		118.051	15.280.41	.1294
	April	80883		80883	10.842.80	.1341
	May	143.086		143.086	13.937.43	.0974
	June	68.376		68.376	17.931.11	.2622
Grand Total		1.453.599		1.453 599	188.335.82	.1296

REMARKS:—

No. 1 is of the Belgian Ladder type of dredge and was originally built and operated by the French Canal Co.

Material excavated consisted of mud and stiff clay to a depth of 42 feet mean sea level.

Costs are for spoil placed on dump and include operation, maintenance, material, plant, survey and all other charges.

Length of haul 4 to 5 nautical miles.

THE PANAMA CANAL

Performance of French Ladder Dredge No. 6

July 1, 1908. — June 30, 1909

Year	Month	Cubic Yards			Cost	Unit Cost
		Earth	Rock	Total		
1908	July	149,832		149,832	22,195.19	.1481
	Aug.	130,210		130,210	26,097.26	.2004
	Sept.	21,971	21,971	43,942	17,044.88	.3879
	Oct.	71,679	31,868	103,547	14,269.08	.1378
	Nov.	17,669	33,630	51,299	18,457.33	.3598
	Dec.	29,259	20,432	49,691	17,704.74	.3562
1909	Jan.	23,368	33,719	57,087	19,744.14	.3459
	Feb.	52,781	16,315	69,096	21,669.71	.3136
	March	18,783	34,344	53,127	24,399.18	.4593
	April	6,303	35,219	41,522	20,592.67	.4959
	May		24,949	24,949	11,501.02	.4609
	June		15,950	15,950	12659.07	.7937
Grand Total		521,855	268,397	790,252	226,331.27	.2864

Remarks:—

Dredge No. 6 is of the Belgian Ladder type and was originall built and operated by the French Canal Co.

Material excavated consisted of mud, clay and rock to a depth of 42 feet mean sea level.

Costs are for material placed on dump and include operation, maintenance, material, plant, survey and all other charges.

Length of haul for spoil 4 to 5 nautical miles.

THE PANAMA CANAL

PERFORMANCE OF FRENCH LADDER DREDGE BADGER

JULY 1, 1908 — JUNE 30, 1909.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1908	JULY	145,835		145,835	13,568.62	.0930
	AUG.	144,890		144,890	16,674.88	.1151
	SEPT.	129,608		129,608	12,103.53	.0934
	OCT.	89,391		89,391	12,170.18	.1361
	NOV.	67,192		67,192	13,014.14	.1937
	DEC.	58,132		58,132	16,551.19	.2847
1909	JAN.	122,790		122,790	16,813.46	.1369
	FEB.	111,468		111,468	16,018.32	.1437
	MARCH	140,141		140,141	18,849.80	.1345
	APRIL	114,047		114,047	14,094.73	.1236
	MAY	81,377		81,377	20,885.89	.2567
	JUNE	5,610		5,610	16,931.20	*3.0180
GRAND TOTAL		1,210,481		1,210,481	187,675.94	.1550

REMARKS:—

THE BADGER IS OF THE BELGIAN LADDER TYPE OF DREDGE AND WAS ORIGINALLY BUILT AND OPERATED BY THE FRENCH CANAL CO.

MATERIAL EXCAVATED CONSISTED MUD AND STIFF CLAY TO A DEPTH OF 45 FEET MEAN SEA LEVEL.

COSTS ARE FOR MATERIAL PLACED IN DUMP AND INCLUDE ALL OPERATION, MAINTENANCE, MATERIAL AND PLANT CHARGES, SURVEYS AND ADMINISTRATIVE CHARGES.

LENGTH OF HAUL 4 TO 5 NAUTICAL MILES.

*DREDGE UNDER REPAIR DURING MONTH.

THE PANAMA CANAL

Performance of French Ladder Dredge Mole
July 1, 1908. — June 30, 1909.

Year	Month	Cubic Yards			Cost	Unit Cost
		Earth	Rock	Total		
1908	July					
	Aug					
	Sept.					
	Oct.	56,340		56,340	6,185.59	.1098
	Nov.	118,250		118,250	17,097.13	.1446
	Dec.	109,430		109,430	12,571.93	.1149
1909	Jan.	78,634		78,634	12,574.51	.1599
	Feb.	39,669		39,669	12,118.17	.3055
	March	125,159		125,159	25,847.36	.2065
	April	98,436		98,436	16,772.05	.1704
	May	87,992		87,992	16,713.03	.1899
	June	118,350		118,350	15,601.20	.1318
Grand Total		832,260		832,260	135,480.97	.1628

Remarks:-

Dredge Mole is of the French Marine type of dredge and was originally built and operated by the French Canal Co.

July 1, 1908 to Oct. 18, 1908 undergoing general overhauling and repairs.

Material excavated consisted of mud and very stiff clay to a depth of 45 feet mean sea level.

Costs are for material placed on dump and include all operation, maintenance, material and plant charges, survey and administrative charges.

Length of haul three to four nautical miles.

THE PANAMA CANAL

Performance of French Ladder Dredge Gopher

July 1, 1908. — June 30, 1909

Year	Month	Cubic Yards Earth	Cubic Yards Rock	Cubic Yards Total	Cost	Unit Cost
1908	July	157,640		157,640	12,823.05	.0813
	Aug.	161,588		161,588	18,422.65	.1140
	Sept.	138,757		138,757	13,683.74	.0986
	Oct.	103,517		103,517	14,126.73	.1365
	Nov.	87,342		87,342	14,844.89	.1700
	Dec.	114,962		114,962	13,062.20	.1136
1909	Jan.	120,618		120,618	12,153.81	.1008
	Feb.	125,958		125,958	13,494.33	.1071
	March	172,477		172,477	17,362.24	.1007
	April	156,070		156,070	21,603.53	.1384
	May	133,620		133,620	16,736.01	.1253
	June	161,395		161,395	16402.83	.1016
Grand Total		1,633,944		1,633,944	184,716.01	.1130

Remarks:—

Dredge Gopher is of the French Marine type of dredge and was originally built and operated by the French Canal Co.

Material excavated consisted of mud and stiff clay to a depth of 45 feet mean tide.

Costs are for material placed on dump and include all operation, maintenance, material and plant charges, survey and administrative charges.

Length of haul 3 to 4 miles.

THE PANAMA CANAL

PERFORMANCE OF FRENCH LADDER DREDGE No. 5.

JULY 1, 1909. — JUNE 30, 1910.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1909	JULY	176082		176.082	32.759.35	.1860
	AUG.	14.160	9.686	23.846	16373.07	6866
	SEPT.	151.841		151841	32.93168	.2169
	OCT.	78.125	19.135	97.260	25.190.34	.2590
	NOV.	44.281	32.341	76622	19.983.02	.2608
	DEC.	47.670		47.670	1767504	3708
1910	JAN.	61.757	10.208	71.965	20.761.90	2885
	FEB.	85.988	5.904	91.892	23.827.60	.2593
	MARCH	60.942	18.813	79.755	18590.89	2331
	APRIL	44844	25.643	70.487	22.922.37	.3252
	MAY	6.266	37.344	43.610	15.498.99	.3554
	JUNE	25370	29.379	54749	2380487	.4348
GRAND TOTAL		797.326	188453	985.779	270.31912	.2742

REMARKS:—

No 5 IS OF THE BELGIAN LADDER TYPE OF DREDGE AND WAS ORIGINALLY BUILT AND OPERATED BY THE FRENCH CANAL CO.

MATERIAL EXCAVATED CONSISTED OF MUD, CLAY AND ROCK TO A DEPTH OF 42 FEET MEAN SEA LEVEL.

COSTS ARE FOR SPOIL PLACED ON DUMP AND INCLUDE OPERATION, MAINTENANCE, MATERIAL, PLANT SURVEY AND ALL OTHER CHARGES.

LENGTH OF HAUL FOR SPOIL 4 TO 5 NAUTICAL MILES.

THE PANAMA CANAL

PERFORMANCE OF FRENCH LADDER DREDGE MARMOT

JAN. 1, 1910. — DEC. 31, 1910.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1910	JAN	128.096		128.096	31.409.14	.2452
	FEB.	121.940		121.940	29.046.11	.2382
	MARCH	121.453		121.453	28.164.95	.2319
	APRIL	98972		98.972	25.544.67	.2581
	MAY	89.785		89.785	27.330.55	.3044
	JUNE	85.640	6.874	92.514	26.736.55	.2890
	JULY	92.437	6.181	98.618	28.128.46	.2852
	AUG.	93.317	4.710	98.027	29.687.61	.3029
	SEPT.	83.827	12.645	96.472	29.936.90	.3103
	OCT.	53677	20.135	73.812	22.955.36	.3110
	NOV.	133.181		133.181	37.330.63	.2803
	DEC.	219.795		219.795	46.860.29	.2132
GRAND TOTAL.		1.322.120	50.545	1.372.665	363.131.22	.2645

REMARKS:—

THE MARMOT IS OF THE BELGIAN LADDER TYPE OF DREDGE AND WAS ORIGINALLY BUILT AND OPERATED BY THE FRENCH CANAL CO.

MATERIAL EXCAVATED CONSISTED OF MUD, CLAY AND ROCK TO A DEPTH OF 45 FEET MEAN SEA LEVEL.

COSTS ARE FOR SPOIL PLACED ON DUMP AND INCLUDE ALL OPERATION MAINTENANCE, MATERIAL, PLANT, SURVEY AND ALL OTHER CHARGES.

LENGTH OF HAUL 4 TO 5 NAUTICAL MILES.

THE PANAMA CANAL

PERFORMANCE OF LADDER DREDGE COROZAL

APRIL 1912 — JAN. 1915.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1912	APRIL	7,421	7,421	14,842	13,289.36	.8954
	MAY	57,531	57,531	115,062	25,129.32	.2184
	JUNE	11,862	11,862	23,724	11,650.86	.4911
	FISCAL YEAR	76,814	76,814	153628	50,069 54	.3259
	JULY	28,365	45,365	73,730	29,852.62	.4043
	AUG.	52,739	52,738	105,477	23,344 92	.2213
	SEPT.	58,500	46,500	105000	32,237.25	.3070
	OCT.	43,804	43,805	87,609	38,622.44	.4409
	NOV.	76,118	80,828	156,946	34,857.71	.2221
	DEC.	42,636	69,564	112,200	31,730.16	.2828
1913	JAN.	27,451	67,209	94,660	32 326.39	.3415
	FEB.	96,164	37,397	133,561	32,642.31	.2444
	MARCH	74,804	49,870	124,674	36,778 83	.2148
	APRIL	63,741	44,662	108,403	40,434.32	.3730
	MAY	64,889	24,964	89,853	36,989.64	.4115
	JUNE	61,388	86,926	148,314	40,741.86	.2747
	FISCAL YEAR	690,599	649,828	1,340,427	410,558.45	.3063
	JULY	23,603	152,971	176,574	40205.90	.2277
	AUG.	20,441	115,830	136,271	37,079.34	.2721
	SEPT.	12,591	111,048	123,639	36,869.15	.2982
	OCT.	32,338	114,655	146,993	52,182.52	.3550
	NOV.	0	95,039	95,039	44,326.19	.4664
	DEC.	43,735	67,197	110,932	36,851.61	.3322
1914	JAN.	1,012	107,545	108,557	45,691 64	.4209
	FEB.	0	90,761	90,761	53,367.47	.5880
	MARCH	0	0	0	54,064.03	*
	APRIL	35,614	57,457	93,071	46,257 90	.4970
	MAY	7,043	112,881	119,924	41,277.84	.3442
	JUNE	0	125,838	125,838	47,415.76	.3768
	FISCAL YEAR	176,377	1,151,222	1327,599	535,589.35	.4034
	JULY	0	58,538	58,538	35,698.79	.6098
	AUG.	22,039	88,155	110,194	35,427.37	.3215
	SEPT.	70,788	35,394	106,182	41,092.43	.3870
	OCT.	14,395	45,616	60,011	27,956.00	.4658
	NOV.	42,376	16,524	58,900	34407.41	.5842
	DEC.	53,561	21,644	75,205	23,992.57	.3190
1915	JAN.	21,674	39,275	60,949	31,672.12	.5196
	TOTAL 7 MONTHS	224,833	305,146	529,979	230,246.69	.4344
GRAND TOTAL		1,168,623	2,183,010	3,351,633	1,226,464 03	.3659

REMARKS:— The COROZAL is a self-propelling center ladder dredge, built in Scotland and operated on the Panama Canal since April 1912.

Material excavated consisted of hard clay and rock to a depth of 45 feet mean sea level.

Length of haul 3 to 4 nautical miles.

Costs are for material placed on dump and include operation, maintenance, material, plant, surveys and all other charges.

* Dredge under repair

THE PANAMA CANAL

Performance of 5 yd Dipper Dredge Cardenos

July 1, 1910. — June 30, 1911.

Year	Month	Cubic Yards			Cost	Unit Cost
		Earth	Rock	Total		
1910	July	54.360	7.583	61.943	22.082.68	.3565
	Aug.	70.287		70.287	24.495.02	.3485
	Sept.	76.200		76.200	25.671.78	.3369
	Oct.	61.240	700	61.940	20.954.30	.3383
	Nov.	48.519	7.379	55.898	19.290.40	.3451
	Dec	22312		22.312	8.005.55	.3588
1911	Jan.	53.177	5.187	58.364	19.813.75	.3395
	Feb.	31.760	18.967	50.727	16.800.78	.3312
	March	58.561	22.450	81.011	23.474.32	.2898
	April	34.474	15.487	49.961	12.705.08	.2543
	May	62.017	21.685	83.702	11.000.69	.1314
	June	71.494		71.494	14.699.17	.2056
Grand Total		644.401	99.438	743.839	218.993.52	.2944

Remarks:

The Cardenos is a 5 yd dipper dredge built in the United States and operated in the Panama Canal since May 1907.

Material excavated consisted of mud, stiff clay and rock to a depth of 45 feet mean sea level.

Costs are for material placed on dump and include all operation, maintenance, material, plant, survey and administrative charges.

Length of haul for spoil 3 to 4 nautical miles.

THE PANAMA CANAL

PERFORMANCE OF 5 YD. DIPPER DREDGE CHAGRES

JULY 1, 1910. — JUNE 30, 1911

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST.
		EARTH	ROCK	TOTAL		
1910	JULY	36374	4020	40394	107247.89	.2655
	AUG.	30.552	9859	40.411	131 0933	3244
	SEPT.	29768	9844	39612	13.12742	3314
	OCT.	32166	6356	38522	1267759	3291
	NOV.	13958	11682	25640	1043548	4070
	DEC.	20164	6483	26647	940106	3528
1911	JAN.	41806	4459	46265	1233425	.2666
	FEB.	29322	2826	32148	422103	1313
	MARCH	20785	13430	34215	149990	4384
	APRIL	19467	18315	37782	1603968	4245
	MAY	15397	13446	28.843	1287263	4463
	JUNE.	24.057	5616	29673	14391.40	4850
GRAND TOTAL		313816	106336	420152	144.33462	3435

REMARKS:—

THE CHAGRES IS A 5 YD. DIPPER DREDGE BUILT IN THE UNITED STATES AND OPERATED ON THE PANAMA CANAL SINCE APRIL 1907.

MATERIAL EXCAVATED CONSISTS OF MUD, CLAY, CORAL ROCK AND ROCK TO A DEPTH OF 42 FEET MEAN SEA LEVEL.

COSTS ARE FOR MATERIAL PLACED ON DUMP AND INCLUDE ALL OPERATION, MAINTENANCE, MATERIAL, PLANT, SURVEY AND ADMINISTRATIVE CHARGES.

LENGTH OF HAUL FOR SPOIL, 5 TO 6 NAUTICAL MILES

THE PANAMA CANAL

Performance of 5 yd. Dipper Dredge Mindi

July 1, 1910 – June 30, 1911

Year	Month	Cubic Yards			Cost	Unit Cost
		Earth	Rock	Total		
1910	July	1,400		1.400	7078 66	50562
	Aug.	35.764	6.360	42.124	14.132.60	.3355
	Sept.	29.262	5.918	35.180	13857.40	3939
	Oct.	23.718	9767	33485	9.68386	.2892
	Nov.	32.528	9.239	41.767	11.247.85	2693
	Dec.	16.914	17.460	34.374	14.213.65	.4135
1911	Jan.	28.945	5.498	34.443	9.792.14	.2843
	Feb.	24.192	500	24.692	6097.54	.2469
	March	47.324		47.324	17.744.28	.3749
	April	26.653	2.247	28.900	12.210.25	.4225
	May	4.073	1.977	6.050	10.537.82	1.7418
	June	31.574	9.478	41.052	12.754.86	.3107
Grand Total		302.347	68.444	370.791	139.350.91	.3758

Remarks:—

The Mindi is a 5 yd dipper dredge built in the United States and operated in the Panama Canal since Dec. 1907.

Material excavated consisted of mud, clay, coral rock and rock to a depth of 42 feet mean sea level.

Costs are for material placed on dump and include all operation, maintenance, material, plant, survey and administrative charges.

Length of haul for spoil 5 to 6 nautical miles.

High costs in July, 1910 and May, 1911 due to extensive repairs.

THE PANAMA CANAL

PERFORMANCE OF DIPPER DREDGE GAMBOA

APRIL 7, 1914 — JAN. 31, 1915.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1914	APRIL		32.805	32.805	22.889.58	.6977
	MAY	4.494	103.691	108.185	55.596.67	.5139
	JUNE	2.965	120.234	123.199	79.044.07	.6416
	FISCAL YEAR	7.459	256.730	264.189	157.530.32	.5963
	JULY		108.896	108.896	59.266.33	.5442
	AUGUST		121.850	121.850	57.099.67	.4686
	SEPT.		111.355	111.355	52.061.26	.4675
	OCT.		137.060	137.060	49.370.66	.3602
	NOV.		140.905	140.905	49.314.22	.3500
	DEC.		166.092	166.092	61.919.10	3728
1915	TOTAL 6 MONTHS		786.158	786.158	329.031.24	.4185
	JAN.		178.370	178.370	58416.18	.3275
	GRAND TOTAL	7.459	1.221.258	1.228.717	544.977.74	*.4243

REMARKS:

THE GAMBOA IS A 15 YD. DIPPER DREDGE BUILT IN THE UNITED STATES AND OPERATED IN CULEBRA CUT OF THE PANAMA CANAL SINCE APRIL 1914.

MATERIAL EXCAVATED CONSISTED OF HARD AND SOFT ROCK TO A DEPTH OF 35 TO 47 FEET.

LENGTH OF HAUL FOR SPOIL 9 TO 10 NAUTICAL MILES.

COSTS ARE FOR MATERIAL PLACED ON DUMP AND INCLUDE OPERATION, MAINTENANCE, MATERIAL, PLANT, SURVEY AND ALL OTHER CHARGES.

A 10 YD. DIPPER WAS USE ON THIS WORK.

* A CREDIT OF $23,680.67 FOR UNUSED SPUDS, BUCKETS, ETC. HAS BEEN ALLOWED IN COMPUTING THE AVERAGE UNIT COST.

THE PANAMA CANAL

PERFORMANCE OF DIPPER DREDGE PARAISO

JUNE 7, 1914.—JAN. 31, 1915.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST.
		EARTH	ROCK	TOTAL		
1914	APRIL					
	MAY					
	JUNE		69.812	69.812	43.649.09	.6252
	FISCAL YEAR		69.812	69.812	43.649.09	.6252
	JULY		82.203	82.203	39.319.69	.4783
	AUGUST		95.475	95.475	54.844.42	.5744
	SEPT.		105.470	105.470	56.703.97	.5376
	OCT.		125.605	125.605	47.338.42	.3769
	NOV.		139.916	139.916	55.621.66	.3975
	DEC.		144.165	144.165	61.137.11	.4241
1915	TOTAL 6 MONTHS		692.834	692.834	314.975.27	.4546
	JAN.		176.862	176.862	55.428.55	.3134
GRAND TOTAL			939.508	939.508	414.052.91	*.4291

REMARKS:—

THE PARAISO IS A 15 YD. DIPPER DREDGE BUILT IN THE UNITED STATES AND OPERATED IN CULEBRA CUT OF THE PANAMA CANAL SINCE JUNE, 1914.

MATERIAL EXCAVATED CONSISTED OF HARD AND SOFT ROCK TO A DEPTH OF 35 TO 47 FEET.

THE LENGTH OF HAUL FOR SPOIL, 9 TO 10 NAUTICAL MILES.

COSTS ARE FOR MATERIAL PLACED ON DUMP AND INCLUDE OPERATION, MAINTENANCE, MATERIAL, PLANT, SURVEY AND ALL OTHER CHARGES.

A 10 YD. DIPPER WAS USED ON THIS WORK.

* A CREDIT OF $10,948.25 FOR UNUSED SPUDS, BUCKETS, ETC. HAS BEEN ALLOWED IN COMPUTING THE AVERAGE UNIT COST.

THE PANAMA CANAL

PERFORMANCE
—OF—
PIPE LINE SUCTION DREDGE No. 4
JULY 1, 1913. – JUNE 30, 1914.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1913	JULY	269.230		269.230	32143.92	.1194
	AUG.	108.019		108.019	14.647.37	.1356
	SEPT.	33.081		33.081	1402849	.4241
	OCT.	83.488		83488	1688576	.2023
	NOV.	39.649	3.796	43445	13734.51	.3161
	DEC	98427	5905	104.332	1834653	1758
1914	JAN.	69.860	10032	79892	22.92359	2869
	FEB.	49278	6824	56102	17534.91	3125
	MARCH	6.778		6.778	11.713.80	*1,7282
	APRIL	103964		103964	16284.65	1566
	MAY	79.705		79705	13.523.38	.1697
	JUNE	100.357		100.357	19996.44	.1992
GRAND TOTAL		1.041.836	26.557	1.068.393	211.763.35	.1982

REMARKS:—

No. 4 IS AN OLD FRENCH LADDER DREDGE REBUILT INTO AN 18 INCH SUCTION DREDGE AT CRISTOBAL DRY DOCK AND PLACED IN COMMISSION IN AUG. 1910.

MATERIAL EXCAVATED CONSISTED OF CLAY, CORAL SAND AND BROKEN ROCK TO ADEPTH OF 42 FEET MEAN SEA LEVEL, AND DELIVED ON THE DUMP THROUTH A 20 INCH PIPE LINE 3000 FEET LONG.

COSTS ARE FOR SPOIL PLACED ON DUMP AND INCLUDE OPERATION, MAINTENANCE, MATERIAL, PLANT, PIPE LINE AND OTHER CHARGES.

* HIGH UNIT COST IN MARCH DUE TO EXTENSIVE REPAIRS.

THE PANAMA CANAL
PERFORMANCE
— OF —
PIPE LINE SUCTION DREDGE No. 82
JULY 1, 1913 — JUNE 30, 1914

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1913	JULY					
	AUG.					
	SEPT.	48.939		48.939	17.412.98	.3558
	OCT.	61.105		61.105	16.559.34	.2709
	NOV.	45.319	5.035	50354	14.854.79	.2951
	DEC.	81.497		81497	17.035 47	.2090
1914	JAN.	64.735	2.389	67.124	10.063.58	.1499
	FEB.	39.900	11.650	51.550	11.216.19	.2176
	MARCH	48.456	8.444	56.900	10.351.09	.1819
	APRIL	44.956	7.484	52.440	8.901.70	.1697
	MAY	45.181		45.181	13.998.51	.3093
	JUNE	46.925		46.925	14.197.74	.3026
GRAND TOTAL		527.013	35.002	562.015	134.591.39	.2395

REMARKS:—

No. 82 IS A 20 INCH SUCTION DREDGE BUILT IN THE UNITED STATES AND PLACED IN COMMISSION IN APRIL 1909.

MATERIAL EXCAVATED CONSISTED OF MUD, CLAY, GRAVEL AND BROKEN ROCK TO A DEPTH OF 42 FEET MEAN SEA LEVEL, AND WAS PUMPED ASHORE THROUGH A 20 INCH PIPE LINE 3000 FEET LONG.

COSTS ARE FOR MATERIAL PLACED ON DUMP AND INCLUDE OPERATION, MAINTENANCE, MATERIAL, PLANT, PIPE-LINE, AND OTHER CHARGES.

THE PANAMA CANAL
PREFORMANCE
— OF —
PIPE LINE SUCTION DREDGE No. 83
JULY 1, 1913.—JUNE 30, 1914.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1913	JULY	99.186		99.186	17.991.95	.1814
	AUG.	21.853		21.853	7.091.30	.3245
	SEPT.	78.670	4573	83.243	14.615.53	.1756
	OCT.	27.068	26.245	53.313	11957.25	.2243
	NOV.	17.374	34.749	52.123	15253.84	.2927
	DEC.	25.128	25.128	50.256	15226.28	.3030
1914	JAN.	26.867	26.867	53734	14868.13	.2767
	FEB.	19.505	36222	55727	11675.12	.2095
	MARCH		25019	25.019	8.303.50	.3319
	APRIL		2264	2.264	12.158.43	*5.3703
	MAY	4489	2544	7.033	23.098.36	*3.2843
	JUNE		18106	18106	10306.92	.5693
GRAND TOTAL		320.140	201.717	521.857	162546.61	.3115

REMARKS:—

No. 83 is a 20 inch suction dredge built in the United States and placed in commission in Dec. 1908.

Material excavated consisted of clay, coral sand, finger coral and coral rock, to a depth of 42 feet mean sea level and delivered to the dump through a 20 inch pipe line 2000 feet long.

Costs are for material placed on dump and include operation, maintenance, material, plant, pipe-line, and other charges.

* High unit costs in April and May due to extensive repairs.

THE PANAMA CANAL

PERFORMANCE
— OF —
PIPE LINE SUCTION DREDGE No. 84
JULY 1, 1913.—JUNE 30, 1914.

Year	Month	Cubic Yards — Earth	Cubic Yards — Rock	Cubic Yards — Total	Cost	Unit Cost
1913	July	139.529		139.529	18.501.57	.1327
	Aug.	69.701		69.701	9.140.49	.1311
	Sept.	107.804		107.804	16.351.87	.1517
	Oct.	42.598		42.598	13.282.64	.3118
	Nov.	6.219	7.306	13.525	9.605.31	.7102
	Dec.	35.913		35.973	15.944.21	.4432
1914	Jan.	135.940		135.940	12.728.30	.0936
	Feb.	61.961	20.654	82.615	11.482.91	.1390
	March	102.848	7.200	110.048	15.601 55	.1418
	April	106.330		106.330	13.214.71	.1244
	May	92.816		92.816	14.121.89	.1521
	June			0	6.028.70	*
Grand Total		901.719	35.160	936.879	156.004.15	.1665

REMARKS:—

No. 84 is a 20 inch suction dredge built in the United States and has been in operation since Sept. 1908.

Material excavated consisted of mud, clay, coral sand and rock to a depth of 42 feet mean sea level and was delivered to the dump through a 20 inch pipe line of 2000 to 3000 feet in length.

Costs are for material placed on dump and include operation, maintenance, material, plant, pipe line, and other charges.

* Dredge under repair.

THE PANAMA CANAL

PERFORMANCE
— OF —
PIPE LINE SUCTION DREDGE No. 85
JULY 1, 1913, to JUNE 30, 1914.

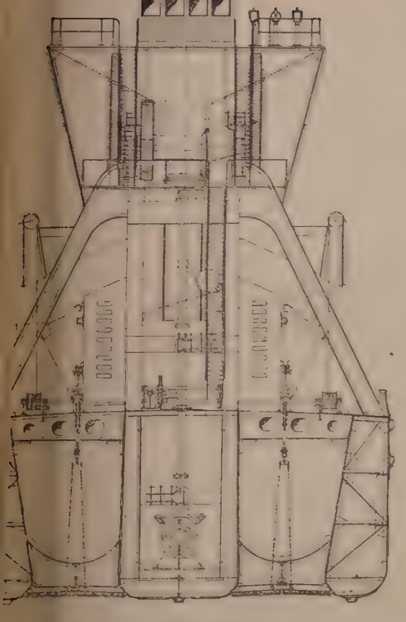
YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1913	JULY	231.105		231.105	15.565 89	0674
	AUG.	286.127		286.127	20.359 10	.0712
	SEPT.	178.579		178.579	20.079.30	.1125
	OCT.	112.904	396	113.300	18.832.58	.1662
	NOV.	30.744	473	31.217	12.663.90	.4057
	DEC.	88.248		88.248	18.895.36	.2141
1914	JAN.	205.656		205.656	15.134.26	.0734
	FEB.	135.150		135.150	19.017.19	.1406
	MARCH	151.672		151.672	18.389.91	.1213
	APRIL	215.524		215.524	18.023 24	.0836
	MAY	143.543		143.543	16.680.56	.1162
	JUNE	123.123		123.123	14.217.87	.1155
GRAND TOTAL		1.902.375	869	1.903.244	207.859.16	.1092

REMARKS:—

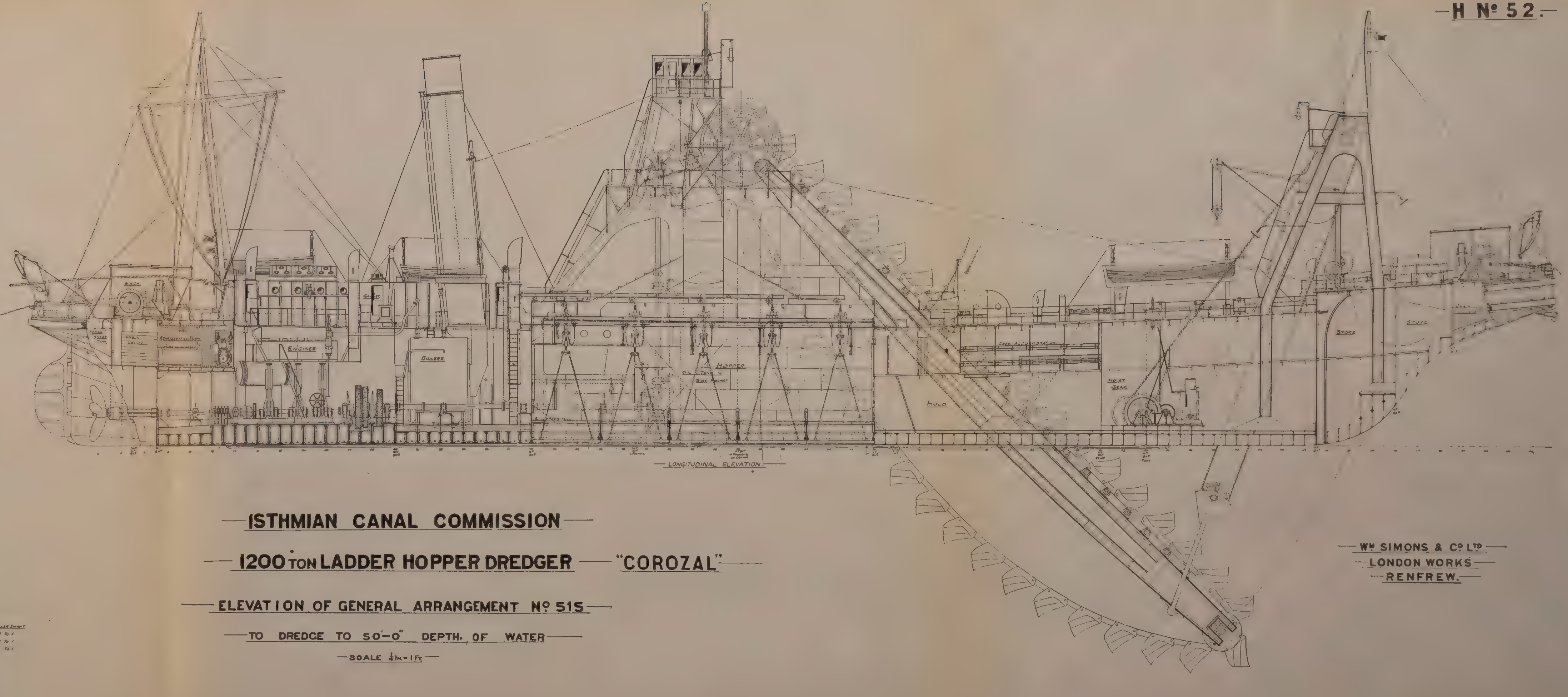
No. 85 is a 20 inch suction dredge built in the United States and placed in commission in Sept. 1908.

Material excavated consisted of mud, sand and clay to a depth of 45 feet, mean sea level, and was delivered on the dump through a 20 inch pipe line 9000 feet using two relays.

Costs are for spoil placed on dump and include operation, maintenance material, plant, pipe line and other charges.



—CROSS SECTION—



—LONGITUDINAL ELEVATION.—

—ISTHMIAN CANAL COMMISSION—

—1200 TON LADDER HOPPER DREDGER — "COROZAL"—

—ELEVATION OF GENERAL ARRANGEMENT Nº 515—

—TO DREDGE TO 50'-0" DEPTH. OF WATER—

—SCALE $\frac{1}{8}$ In = 1 Ft—

—Wm SIMONS & Co Ltd—
—LONDON WORKS—
—RENFREW.—

—DIMENSIONS—

Length overall .... 263 - 9
Length between Perps .... 259 - 0"
Depth, Moulded .... 19 - 5"
Length on load water line ....
Draft, Maximum .... 12 - 0"
Breadth, Moulded .... 45 - 0"
Propelling Speed Knots Per Hour 10
Gross Tonnage 1700
Fuel Capacity .... 387 Bls
2-Engines-3 Cyl Compound $\frac{17 \times 27 \times 45}{27}$ ... 960 IHP Ea
Comod. Dredging And Propelling ... 1920 HP
2 Boilers Scotch Marine, 174" Dia, 2000 HP
126" Long, 1000 HP Each, Fuel Oil
Heating Surface, 2022 Sq Ft Each ... 4044 Sq Ft
Grate Area, 66 Sq Ft Each ... 132 Sq Ft
2-Propellers-111" Dia, 144" Pitch, Shaft 10"
Four Blades, Cast Iron, Solid, R & L
Capacity Large Sized Buckets ... 50 Cu Ft
Capacity Small Sized Buckets ... 35 Cu Ft
Capacity-1200 Cu Yd Mud Per Hour, Cont. 600 Cu Yd
Capacity-Hoppers, Comod ... 27500 Cu Ft

Ratio Of Crank Shaft To Tumbler Shaft
Slow Speed .... 247 To 1
Medium Speed .... 207 To 1
Fast Speed .... 161 To 1

Buckets Per Min	Revolutions Of Engine		
	Slow	Med	Fast
10	988	828	644
12	1185	993	772
14	1383	1159	991
16	155[illegible]	1329	103[illegible]
18	1778	149[illegible]	1159
20	1975	1656	1288

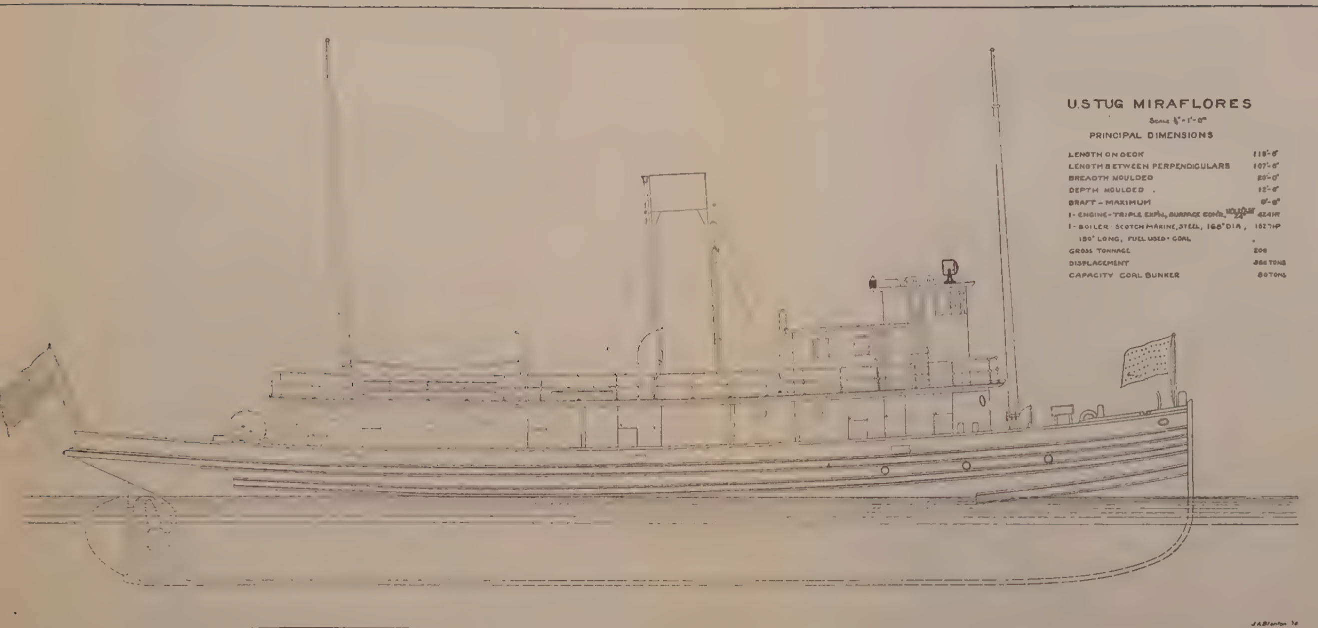

U.S TUG MIRAFLORES
PRINCIPAL DIMENSIONS
LENGTH ON DECK
LENGTH BETWEEN PERPENDICULARS 107'-6"
BREADTH MOULDED
DEPTH MOULDED 12'-6"
DRAFT – MAXIMUM
1 - ENGINE - TRIPLE EXP'N, SURFACE COND'R, 424 HP
1 - BOILER SCOTCH MARINE, STEEL, 168" DIA,
150" LONG, FUEL USED - COAL
GROSS TONNAGE
DISPLACEMENT
CAPACITY COAL BUNKER 80 TONS

Plate XI.

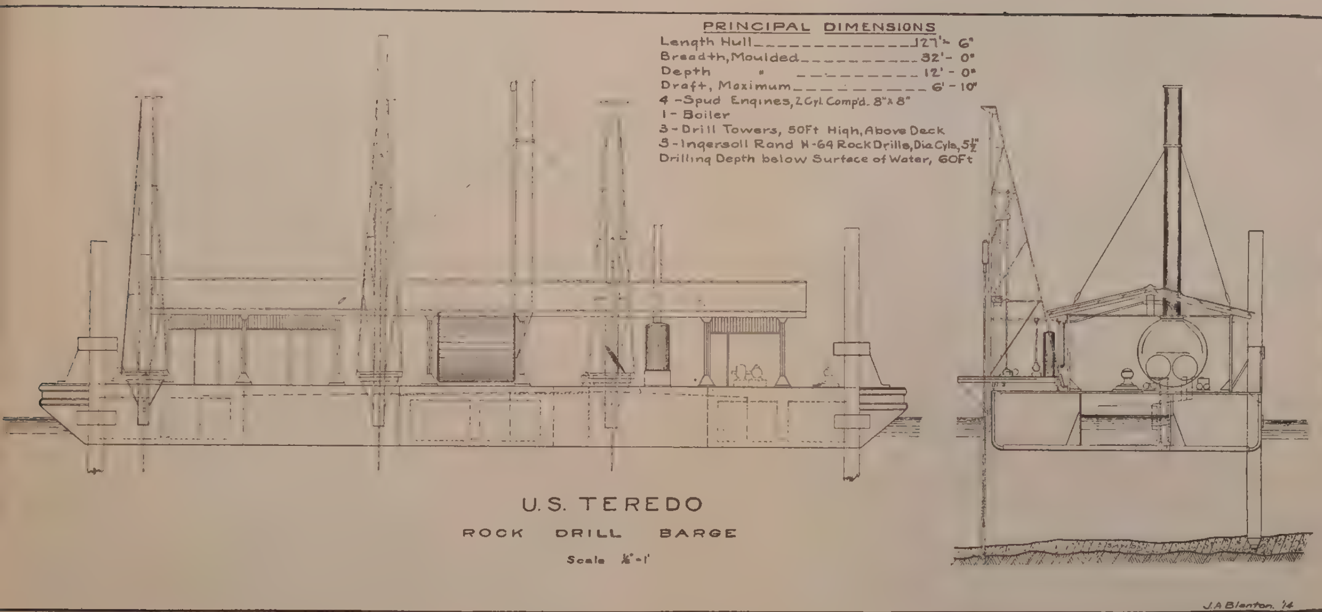

PRINCIPAL DIMENSIONS
Length Hull .... 127'- 6"
Breadth, Moulded .... 32'- 0"
Depth " .... 12'- 0"
Draft, Maximum .... 6'- 10"
4 - Spud Engines, 2 Cyl. Comp'd. 8" x 8"
1 - Boiler
3 - Drill Towers, 50 Ft High, Above Deck
3 - Ingersoll Rand N-64 Rock Drills, Dia. Cyls. 5½"
Drilling Depth below Surface of Water, 60 Ft
U. S. TEREDO
ROCK DRILL BARGE
Scale ⅛" = 1'
J. A. Blanton. '14

Plate XII.

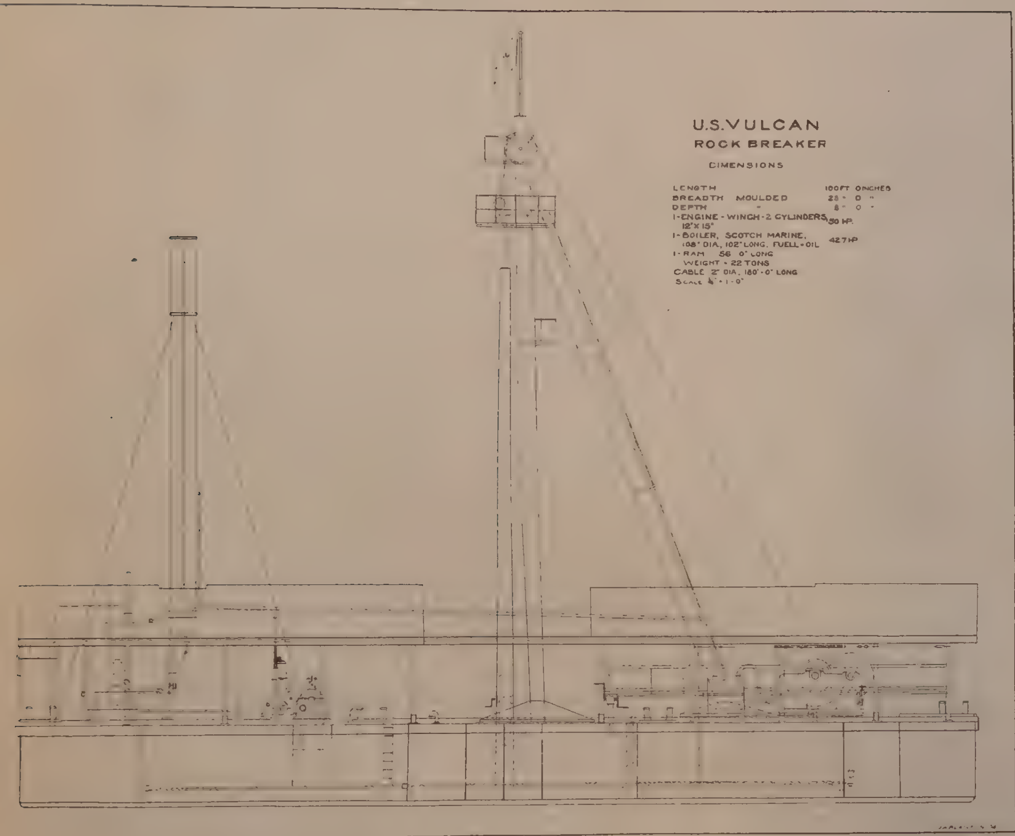
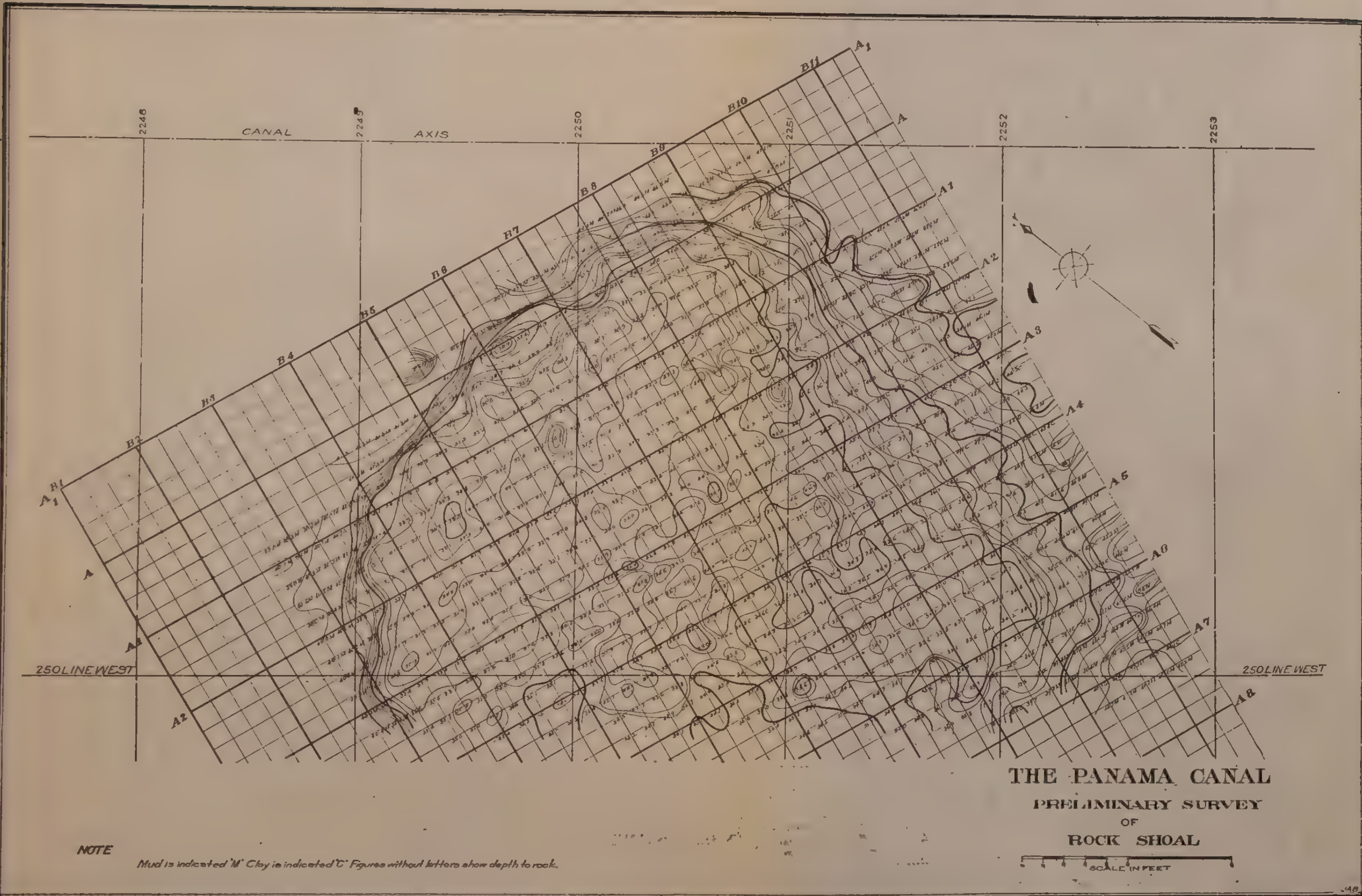

U.S. VULCAN
ROCK BREAKER
CIMENSIONS
LENGTH 100FT 0INCHES
BREADTH MOULDED 28 " 0 "
DEPTH " 8 " 0 "
1-ENGINE - WINCH - 2 CYLINDERS, 12"X 15" 30 HP.
1-BOILER, SCOTCH MARINE, 108" DIA, 102" LONG, FUELL - OIL 427 HP
1-RAM 56 0" LONG
WEIGHT - 22 TONS
CABLE 2" DIA, 180' - 0" LONG
SCALE ¼" - 1 - 0"

Plate XIII.



CANAL AXIS
2248
2249
2250
2251
2252
2253
250 LINE WEST
250 LINE WEST
THE PANAMA CANAL
PRELIMINARY SURVEY
OF
ROCK SHOAL
SCALE IN FEET
NOTE
Mud is indicated "M" Clay is indicated "C" Figures without letters show depth to rock.

Plate XIV.

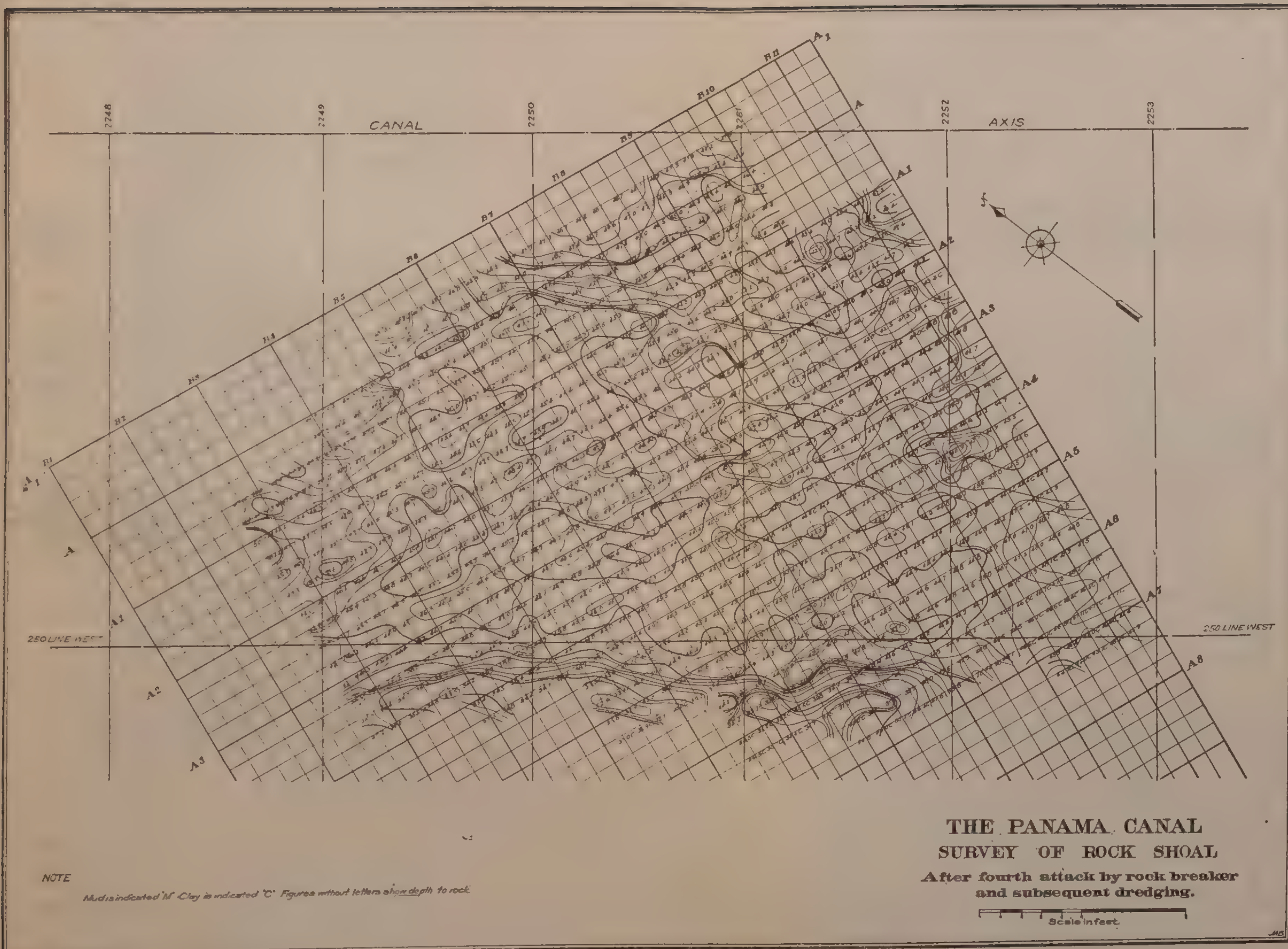

CANAL AXIS
2248
2249
2250
2251
2252
2253
250 LINE WEST
NOTE
Mud is indicated 'M' Clay is indicated 'C' Figures without letters show depth to rock
THE PANAMA CANAL
SURVEY OF ROCK SHOAL
After fourth attack by rock breaker and subsequent dredging.
Scale in feet

Plate XV.

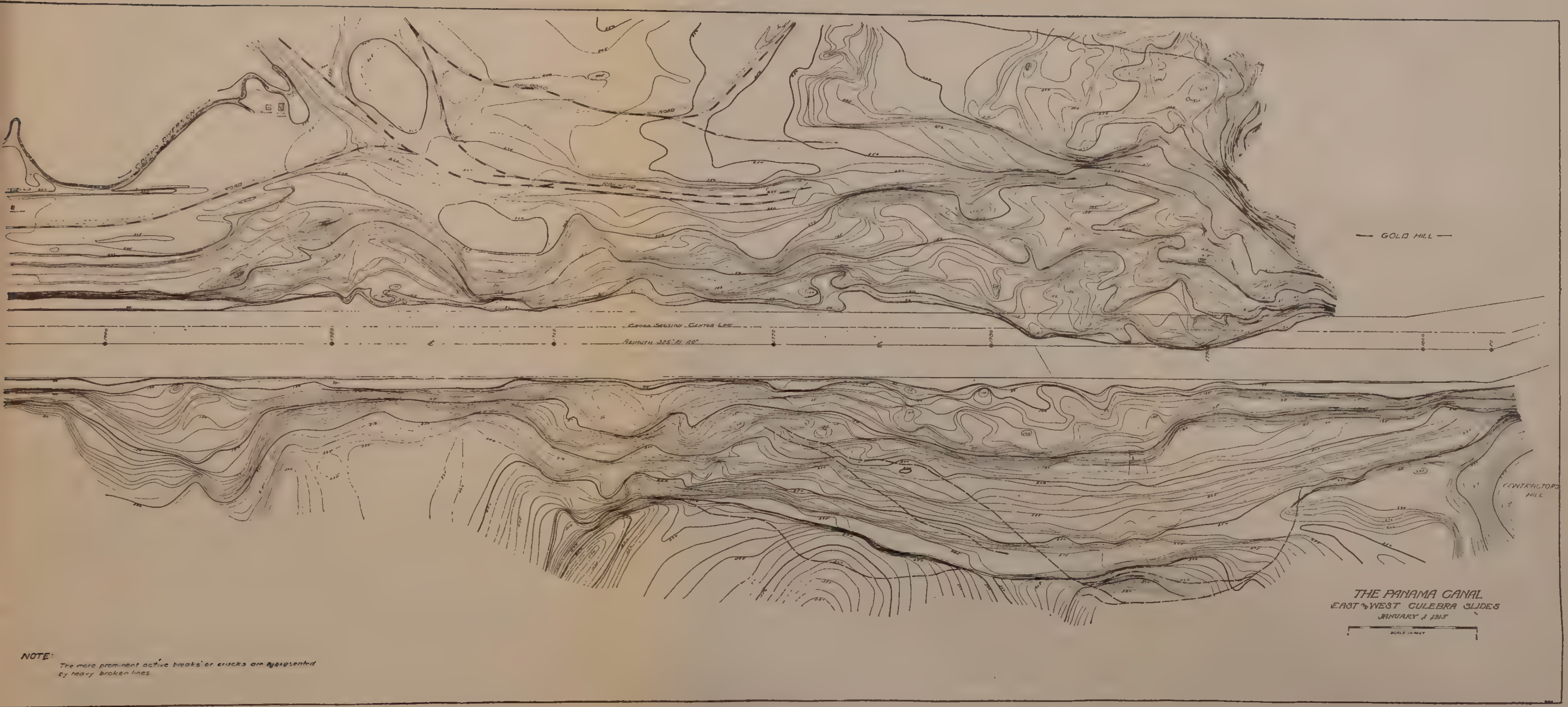

GOLD HILL
CONTRACTORS HILL
RAILROAD
ROAD
CROSS SECTION CENTER LINE
THE PANAMA CANAL
EAST & WEST CULEBRA SLIDES
JANUARY 1 1915
NOTE:
The more prominent active breaks or cracks are represented
by heavy broken lines

Plate XVI.

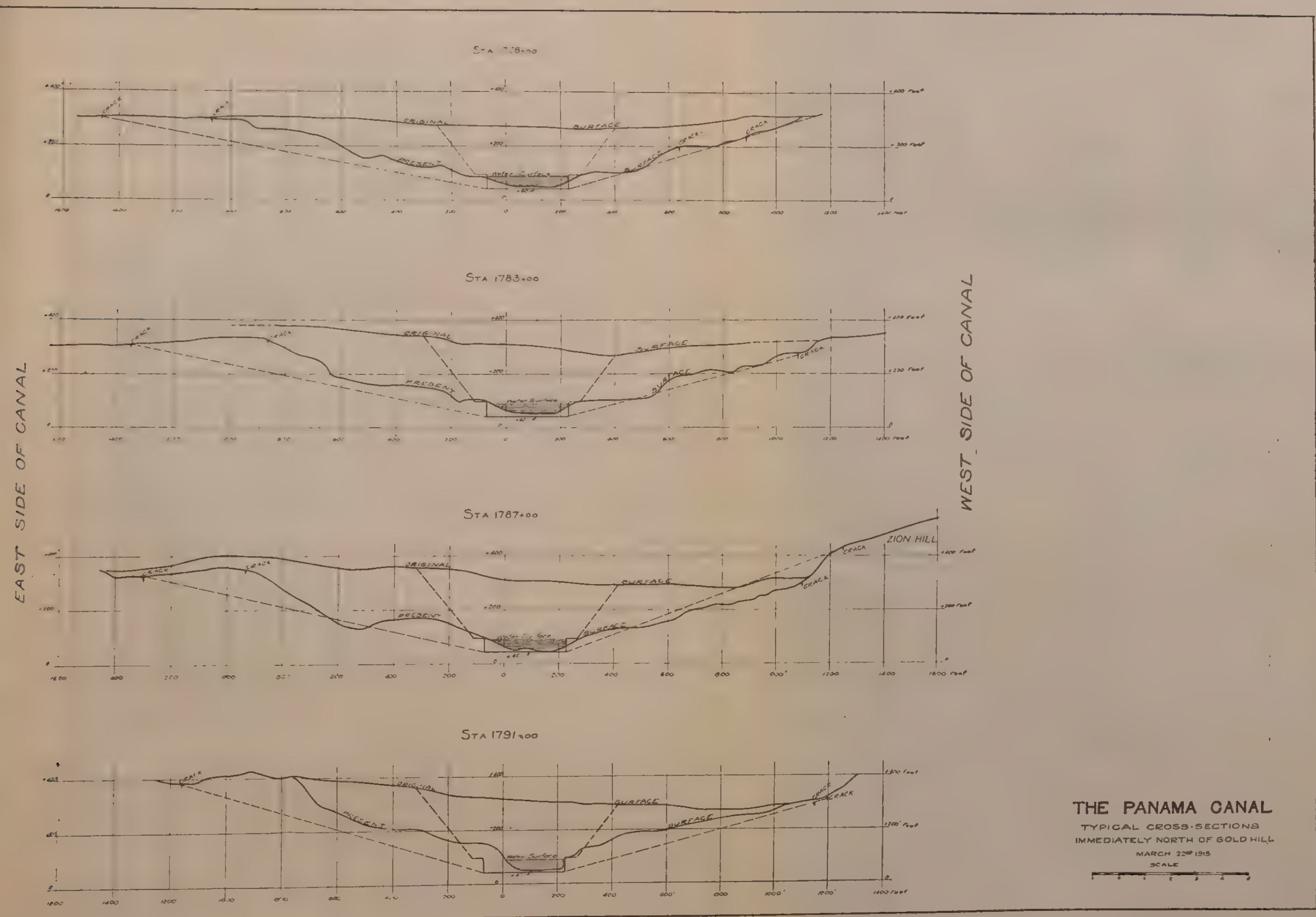

STA 1783+00
STA 1787+00
STA 1791+00
ORIGINAL
SURFACE
PRESENT
CRACK
Water Surface
ZION HILL
EAST SIDE OF CANAL
WEST SIDE OF CANAL
THE PANAMA CANAL
TYPICAL CROSS-SECTIONS
IMMEDIATELY NORTH OF GOLD HILL
MARCH 22ND 1915
SCALE

Plate XVII.

THE PANAMA CANAL

PERFORMANCE

PIPE LINE SUCTION DREDGE No. 86

JULY 1, 1913. – JUNE 30, 1914.

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1913	JULY	194.830		194.830	15.807.33	.0811
	AUG.	171.851		171.851	13.085.66	.0761
	SEPT.	116.385		116.385	15.976.49	.1373
	OCT.	23.824		23.824	19.589.97	*.8223
	NOV.	69.254	516	69770	20.046.65	.2873
	DEC.	64.775	10004	74.779	20.401.98	.2728
1914	JAN.	41.667	7.300	48.967	17.145.14	.3501
	FEB.	48.503	6.277	54.780	18.369.75	.3353
	MARCH	99.454	7.212	106.666	33.487.68	.3140
	APRIL	139.258	3.417	142.675	34.360.05	.2408
	MAY	94.244	9.749	103.993	24.982.86	.2402
	JUNE	86.400	9.600	96.000	22.773.87	.2372
GRAND TOTAL		1.150.445	54.075	1.204.520	256,027.43	.2126

REMARKS:—

No. 86 is a 20 inch suction dredge built in the United States and placed in comission in June, 1910.

Material excavavated consisted of clay and broken rock to a depth of 42 feet and delivered on dump through a 20 inch pipe line 7000 feet long using one relay.

Costs are for spoil placed on dump and include operation, maintenance, material, plant, pipe line and all other charges.

* High unit cost in October due to using dredge to fill cut South of Cucaracha Slide with water.

THE PANAMA CANAL

PERFORMANCE
OF
SEA GOING SUCTION DREDGE CULEBRA
JULY 1, 1909 – JUNE 30, 1910

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1909	JULY	309.100		309100	1242311	0402
	AUG.	151.870		151870	2187828	.1441
	SEPT.	324.570		324570	20.21113	.0623
	OCT.	382.952		382952	1377745	.0360
	NOV.	334843		334843	1515245	.0453
	DEC.	342.395		342.395	1662639	0486
1910	JAN.	271.761		271764	4241466	1561
	FEB.	39152		39.152	2998750	*7659
	MARCH	149959		149.959	4674837	3118
	APRIL	261350		261350	4092414	1566
	MAY	259.991		259991	3957994	.1522
	JUNE	271.079		271079	3930496	.1450
GRAND TOTAL		3.099022		3099022	339028.38	.1094

REMARKS:-

The Culebra is a self-propelling sea going suction dredge built in the United States and operated on the Panama Canal since January 1908.

Material excavated consisted of mud, sand and clay to a depth of 4-5 feet mean sea level.

Length of haul for spoil 4 to 5 nautical miles.

Costs are for spoil placed on dump and include all operation, maintenance, material, plant, survey and administrative charges.

* High cost in February due to extensive repairs.

THE PANAMA CANAL

PERFORMANCE

— OF —

SEA GOING SUCTION DREDGE CARIBBEAN

JULY 1, 1909 – JUNE 30 1910

YEAR	MONTH	CUBIC YARDS			COST	UNIT COST
		EARTH	ROCK	TOTAL		
1909	JULY	393102		393,102	,245475	0317
	AUG.	307914		307914	,487727	0483
	SEPT.	169.978		169978	2354248	1385
	OCT.	335571		335,571	,396152	.0416
	NOV.	346290		346290	,311461	.0379
	DEC.	368600		368600	11,486.14	0312
1910	JAN.	327360		327.360	36.23249	.1107
	FEB.	267.840		267840	32.622.91	.1218
	MARCH	188790		188790	29.24357	1549
	APRIL	0		0	31.042.57	*
	MAY	301.320		301.320	35224.31	.1169
	JUNE	310029		3,10029	3797855	.1225
GRAND TOTAL		3316734		3316794	291.78117	0880

REMARKS:-

THE CARIBBEAN IS A SELF-PROPELLING SEA GOING SUCTION DREDGE BUILT IN THE UNITED STATES AND OPERATED ON THE PANAMA CANAL SINCE AUGUST, 1907.

MATERIAL EXCAVATED CONSISTED OF MUD, CORAL SAND AND CLAY TO A DEPTH OF 42 FEET MEAN SEA LEVEL.

LENGTH OF HAUL FOR SPOIL, 4 TO 5 NAUTICAL MILES.

COSTS ARE FOR MATERIAL PLACED ON DUMP AND INCLUDE ALL OPERATION, MAINTENANCE, MATERIAL, PLANT, SURVEY AND ADMINISTRATIVE CHARGES.

* DREDGE UNDERGOING REPAIRS.

Wage Scale for the Dredging Division, the Panama Canal, Including Only Representative Crews of the Various Floating Equipment.

April 1, 1915.

Number	Designation	Rate of Pay
1	Resident Engineer	$625.00
1	Supt. of Dredging	350.00
1	Supt. of Dredging	300.00
3		
	Office	
1	Chief Clerk	200.00
2	Clerk	175.00
2	"	150.00
1	"	137.50
5	"	125.00
2	Foreman (Material)	150.00
1	Foreman (Timekeeping)	125.00
2	Draftsman	175.00
16		
	Dredging (General)	
1	Supr. of Dredging	225.00
1	General Foreman	200.00
1	General Foreman	165.00
2	Supervising Engineer	225.00
5		
	Surveys	
2	Junior Engineer	200.00
2	Transitman	175.00
3	Transitman	150.00
5	Levelman	125.00
1	Levelman	112.50
1	Levelman	100.00
8	Rodman	83.33
1	Inspector	100.00
23		

U. S. Caribbean

Seagoing suction dredge
(Operating 24 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$257.25
1	Mate (1st)	160.00
1	Mate (2nd)	145.00
1	Mate (3rd)	135.00
1	Steward	132.50
1	Engineer (Chief)	230.00
1	Engineer (1st Asst.)	160.00
1	Engineer (2nd Asst.)	145.00
1	Engineer (3rd Asst.)	135.00
9		

Silver

Number	Designation	Rate of Pay
1	Carpenter	60.00
7	Winchman	50.00
4	Boatswain	45.00
1	Seaman	35.00
9	Seaman	30.00
13	Oiler	55.00
8	Fireman	50.00
1	Fireman	45.00
5	Coal Passers	50.00
1	Cook	60.00
1	Cook	40.00
1	Cook	35.00
1	Waiter	25.00
3	Waiter	17.50
2	Waiter	15.00
58		

U. S. Gamboa

15-yard dipper dredge
(Operating 24 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$243.00
2	Operator	225.75
1	Operator	215.00
1	Mate (Craneman)	210.90
2	Mate (Craneman)	190.00
1	Engineer (Chief)	220.00
3	Engineers	175.00
11		

Silver

3	Watertender	55.00
2	Boatswain	55.00
2	Winchman	55.00
13	Oiler	50.00
6	Fireman	50.00
1	Blacksmith	50.00
1	Cook	50.00
1	Clerk	45.00
1	Carpenter	45.00
6	Seaman	40.00
6	Seaman	35.00
9	Seaman	30.00
1	Storekeeper	30.00
3	Cooks	30.00
1	Waiter	20.00
1	Waiter	15.00
57		

U. S. Cardenas

5-yard dipper dredge

(Operating 24 hours)

Gold

Number	Designation	Rate of Pay
3	Master (Operator)	$210.00
3	Mate (Craneman)	185.00
3	Engineers	155.00
9		

Silver

4	Oiler	55.00
2	Boatswain	55.00
4	Fireman	50.00
12	Seaman	40.00
1	Seaman	35.00
5	Seaman	30.00
2	Clerks	30.00
30		

U. S. Gopher

French ladder dredge (marine)
(Operating 12 hours)
Gold

Number	Designation	Rate of Pay
1	Master	$185.00
1	Engineer (Chief)	175.00
—		
2		

Silver

1	Mate	80.00
1	2nd Engineer	75.00
2	Oiler	55.00
4	Fireman	50.00
1	Winchman	55.00
7	Winchman	50.00
1	Cook	50.00
3	Seaman	40.00
1	Seaman	30.00
—		
21		

U. S. Marmot

French ladder dredge
(Operating 24 hours)
Gold

Number	Designation	Rate of Pay
1	Engineer (Chief)	$175.00
2	Engineer (Asst.)	170.00
—		
3		

Silver

2	Captain	100.00
2	Mate	80.00
4	Oiler	50.00
4	Fireman	50.00
10	Winchman	50.00
8	Cook	50.00
1	Carpenter	45.00
3	Seaman	40.00
2	Seaman	35.00
6	Seaman	30.00
1	Watchman	37.50
—		
43		

U. S. Corozal
Seagoing ladder dredge
(Operating 24 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$220.00
1	Mate (1st)	195.00
1	Mate (2nd)	185.00
1	Engineer (Chief)	220.00
1	Engineer (1st Asst.)	195.00
2	Engineer (Asst.)	185.00
1	Steward	120.00
8		

Silver

2	Captain	100.00
1	Mate	75.00
2	Engineer	75.00
1	Splicer	60.00
2	Boatswain	55.00
6	Winchman	55.00
3	Winchman	50.00
2	Watertender	55.00
10	Oiler	55.00
1	Cook	50.00
1	Cook	45.00
1	Cook	40.00
6	Fireman	50.00
1	Carpenter	45.00
26	Seaman	40.00
7	Seaman	35.00
7	Seaman	30.00
2	Boatman	37.50
1	Storeman	37.50
1	Waiter	20.00
3	Waiter	17.50
86		

U. S. No. 86
Pine-line suction dredge
(Operating 24 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$220.00
1	Mate	195.00
1	Mate	155.00
1	Mate	135.00
1	Engineer (Chief)	204.75
1	Engineer (1st Asst.)	155.00
1	Engineer (2nd Asst.)	135.00
1	Operator	170.00
2	Operator	155.00
1	Foreman	120.00
11		

Silver

Number	Designation	Rate of Pay
3	Watertender	55.00
3	Oiler	55.00
1	Cook	50.00
1	Fireman	45.00
1	Carpenter	45.00
3	Fireman	40.00
1	Cook	40.00
1	Cook	25.00
1	Blacksmith	40.00
1	Clerk	40.00
9	Seaman	35.00
24	Seaman	30.00
1	Waiter	30.00
1	Waiter	15.00
51		

U. S. Reliance
Large tug boat
(Operating three 8-hour shifts)

Gold

Number	Designation	Rate of Pay
1	Master	$185.00
1	Mate	175.00
1	Mate	165.00
1	Engineer (Chief)	175.00
2	Engineers	170.00
6		

Silver

Number	Designation	Rate of Pay
3	Oiler	$ 55.00
2	Fireman	50.00
4	Fireman	45.00
1	Cook	50.00
3	Boatswain	45.00
2	Cook	45.00
10	Seaman	40.00
5	Seaman	35.00
1	Seaman	30.00
1	Waiter	20.00
2	Waiter	15.00
34		

U. S. Bolivar

Large tug boat

(Operating two 9-hour shifts)

Gold

Number	Designation	Rate of Pay
1	Master	$185.00
1	Mate	175.00
1	Engineer (Chief)	175.00
1	Engineer	170.00
4		

Silver

2	Oiler	55.00
1	Oiler	50.00
2	Fireman	50.00
2	Fireman	45.00
2	Boatswain	45.00
1	Cook	50.00
1	Cook	35.00
4	Seaman	40.00
3	Seaman	35.00
5	Seaman	30.00
1	Waiter	15.00
24		

U. S. Chame

Tender

(Operating two 12-hour shifts)

Gold

Number	Designation	Rate of Pay
1	Master	$185.00
1	Mate	175.00
1	Engineer (Chief)	175.00
1	Engineer	170.00
4		

Silver

Number	Designation	Rate of Pay
1	2nd Engineer	67.50
1	Oiler	55.00
2	Oiler	50.00
1	Fireman	50.00
2	Fireman	45.00
1	Cook	50.00
1	Boatswain	45.00
1	Seaman	40.00
2	Seaman	35.00
2	Seaman	30.00
1	Waiter	15.00
15		

U. S. De Lesseps

Small tug boat

(Operating 10 hours)

Gold

Number	Designation	Rate of Pay
1	Mate	$155.00
1		

Silver

Number	Designation	Rate of Pay
1	Engineer	75.00
1	2nd Engineer	65.00
2	Fireman	50.00
1	Boatswain	45.00
1	Cook	40.00
2	Seaman	40.00
1	Seaman	35.00
2	Seaman	30.00
1	Waiter	15.00
12		

U. S. Sanidad
Small tug boat
(Operating three 8-hour shifts)
Gold

Number	Designation	Rate of Pay
1	Master	$170.00
1	Mate	155.00
1	Mate	145.00
1	Engineer	135.00
—		
4		

Silver

Number	Designation	Rate of Pay
2	Engineer	75.00
1	Fireman	50.00
2	Fireman	45.00
3	Seaman	40.00
4	Seaman	35.00
5	Seaman	30.00
—		
17		

U. S. Clapet No. 1
(Operating 9 hours)
Gold

Number	Designation	Rate of Pay
1	Master	$170.00
1	Engineer	155.00
—		
2		

Silver

Number	Designation	Rate of Pay
1	Oiler	55.00
2	Fireman	50.00
1	Boatswain	45.00
1	Cook	45.00
5	Seaman	35.00
8	Seaman	30.00
1	Waiter	17.50
—		
19		

U. S. Clapet No. 4
(Operating two 9-hour shifts)
Gold

Number	Designation	Rate of Pay
1	Mate	$155.00
1	Mate	145.00
2	Engineer	145.00
—		
4		

Silver

2	Oiler	50.00
2	Fireman	50.00
1	Fireman	45.00
2	Boatswain	45.00
1	Seaman	40.00
3	Seaman	35.00
8	Seaman	30.00
1	Cook	35.00
1	Cook	30.00
21		

U. S. Clapet No. 6
(Operating two 12-hour shifts)

Silver

Number	Designation	Rate of Pay
2	Captain	$ 85.00
2	Mate	75.00
2	Engineer	75.00
2	Engineer	65.00
1	Fireman	50.00
1	Fireman	45.00
8	Seaman	40.00
18		

U. S. La Valley
Crane boat
(Operating 9 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$190.00
1	Engineer	194.25
2		

Silver

1	Fireman	75.00
1	Oiler	55.00
3	Fireman	50.00
1	Cook	50.00
1	Boatswain	45.00
6	Seaman	40.00
2	Seaman	35.00
1	Waiter	15.00
16		

U. S. Grader No. 1
Hydraulic Grader
(Operating 9 hours)

Gold

Number	Designation	Rate of Pay
1	Master	$175.00
1	Mate	145.00
1	Engineer	165.00
—		
3		

Silver

2	Oiler	50.00
3	Fireman	50.00
1	Cook	50.00
1	Cook	40.00
1	Carpenter	45.00
6	Seaman	35.00
8	Seaman	30.00
2	Waiter	15.00
—		
24		

U. S. Vulcan
Rock Breaker
(Operating two 8-hour shifts)

Gold

Number	Designation	Rate of Pay
2	Foreman	$170.00
1	Engineer	170.00
1	Engineer	160.00
—		
4		

Silver

4	Winchman	50.00
2	Fireman	50.00
1	Cook	50.00
1	Cook	40.00
1	Seaman	35.00
6	Seaman	30.00
—		
15		

U. S. Teredo No. 2

Drill boat

(Operating two 8-hour shifts)

Gold

Number	Designation	Rate of Pay
1	Master	$200.00
1	Mate	175.00
1	Blacksmith	140.00
1	Engineer	140.00
9	Drill Runners	140.00
13		

Silver

Number	Designation	Rate of Pay
1	2nd Engineer	67.50
1	Fireman	50.00
1	Fireman	45.00
15	Seaman	40.00
6	Seaman	35.00
21	Seaman	30.00
45		

(All gold rates are reduced $20.00 a month when subsistence is supplied.)

Number of Employees in the Dredging Division, March, 1915

Gold	314
Silver	2023
Total	2337